NEW YORK TIMES photo by ERNIE SISTO

Mr. and Mrs. William L. Laurence talking with Dr. Albert Einstein in his study at Princeton, January 1950

About the Author: William L. Laurence, said Dr. J. Bronowski in a recent *Observer* article, "holds a high and special place in American scientific journalism." He has been Science Reporter of the *New York Times* since 1930. He was awarded the Pulitzer Prize for journalism in 1937. Among important developments which he was the first to report were the discoveries of the sulfa drugs, penicillin, ACTH and cortisone. In 1944 he was selected by the U.S. Government to visit the secret atomic war-plants and to write a series of reports for release after the attack on Japan. He was the only newspaper man to witness the first test explosion in New Mexico, and also accompanied the mission which bombed Nagasaki. These reports won him the Pulitzer Prize a second time in 1946, and also formed the material for his earlier book, *Dawn over Zero*.

The H. Hell Bomb

WILLIAM L. LAURENCE

HOLLIS & CARTER

"The most authoritative book yet written about the hydrogen bomb"—
THE DAILY TELEGRAPH

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THE HELL BOMB

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William L. Laurence

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To *FLORENCE*

FOREWORD

THE material in this book falls into two categories: (1) a popular version in terms understandable to the layman of technical data published in scientific literature in this country and abroad, and widely known among scientists everywhere; and (2) technical conclusions reached by deduction based on these published facts and theory, for which I assume the sole responsibility. In doing so, I wish to make it emphatically clear that I have had no access to any classified information on the current hydrogen-bomb program, and also that whatever access I had to H-bomb information during my stay at Los Alamos in the spring and summer of 1945 was strictly limited to the somewhat vague and general discussions carried on there in 1945 and earlier.

I hereby take the opportunity to express my profound appreciation to Dr. James G. Beckerley, Director of Classification, Atomic Energy Commission, Washington, D. C., and to Mr. Corbin Allardice, Director, Public Information Service, of the AEC's New York Operations Office, for their generous co-operation in clearing this manuscript for publication. It must be strictly understood that any such clearance merely means that the AEC

has "no objection to publication" on the grounds of security. It does not in any way vouch for the accuracy or correctness of the book's contents.

WILLIAM L. LAURENCE

New York City
July 30, 1950

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INTRODUCTION

"Democracy Depends on an Informed Electorate"

"It is most important in our democracy that our government be frank and open with the citizens. In a democracy it is only possible to have good government when the citizens are well informed. It is difficult enough for them to become well informed when the information is easily available. When that information is not available, it is impossible. While there may be some cases in which the information which the citizen needs, in order to make an intelligent judgment of national policy, must be kept secret, so that military potential will not be jeopardized, the present use of secrecy far exceeds this minimum limit. These are the methods of an authoritarian government and should be vigorously opposed in our democracy. . . .

"The citizen must choose insofar as that is possible. Today, if he tries to come to some conclusion about what should be done to increase the national security, the citizen runs up against a high wall of secrecy. He can, of course, take the easy solution and say that these are questions which should be left to the upper echelons of the military establishment to decide. But these questions are so important today, that to leave them to the military men to decide is for the citizen essentially to abrogate his basic responsibility. If, in time of peace, questions on which the future of our country depends are left to any small group, not representative

of the people, to decide, we have gone a long way toward authoritarian government.

"The United States has grown to be a strong nation under a constitution which wisely has laid great emphasis upon the importance of free and open discussion. Urged by a large number of people who have fallen for the fallacy that in secrecy there is security, and, I regret, encouraged by many, including eminent scientists, to prophesy doom just around the corner, we are dangerously close to abandoning those principles of free speech and open discussion which have made our country great. The democratic system depends on making intelligent decisions by the electorate. Our democratic heritage can only be carried on if the citizen has the information with which to make an intelligent decision."

(From a talk on the hydrogen bomb, March 27, 1950, at Town Hall, Los Angeles, by PROFESSOR ROBERT F. BACHER, head of the Physics Department, California Institute of Technology. Professor Bacher served as the first scientific member of the Atomic Energy Commission and was one of the major architects of the atomic bomb at Los Alamos, New Mexico.)

THE HELL BOMB

I

THE TRUTH ABOUT THE HYDROGEN BOMB

I FIRST heard about the hydrogen bomb in the spring of 1945 in Los Alamos, New Mexico, where our scientists were putting the finishing touches on the model-T uranium, or plutonium, fission bomb. I learned to my astonishment that, in addition to this work, they were already considering preliminary designs for a hydrogen-fusion bomb, which in their lighter moments they called the "Super-duper" or just the "Super."

I can still remember my shock and incredulity when I first heard about it from one of the scientists assigned to me by Dr. J. Robert Oppenheimer as guides in the Dantesque world that was Los Alamos, where the very atmosphere gave one the sense of being in the presence of the supernatural. It seemed so fantastic to talk of a superatomic bomb even before the uranium, or the plutonium, bomb had been completed and tested—in fact, even before anybody knew that it would work at all—that I was inclined at first to disbelieve it. Could anything be more powerful, I found myself thinking, than a weapon that, on paper at least, promised to release an explosive force of 20,000 tons of TNT? It was a screwball world, this world

of Los Alamos, I kept saying to myself, and this was just a screwball notion of my younger scientific mentors.

So at the first opportunity I put the question to Professor Hans A. Bethe, of Cornell University, one of the world's top atomic scientists, who headed the elite circle of theoretical physicists at Los Alamos. Dr. Bethe, I knew, was the outstanding authority in the world qualified to talk about the subject, since he was the very man who first succeeded in explaining how the fusion of hydrogen in the sun is the source of energy that will make it possible for life to continue on earth for billions of years.

"Is it true about the superbomb?" I asked him. "Will it really be as much as fifty times as powerful as the uranium or plutonium bomb?"

I shall never forget the impact on me of his quiet answer as he looked away toward the Sangre de Cristo (Blood of Christ) mountain range, their peaks turning blood-red in the New Mexico twilight. "Yes," he said, "it could be made to equal a million tons of TNT." Then, after a pause: "Even more than a million."

The tops of the mountains seemed to catch fire as he spoke.

Long before it was discovered that vast amounts of energy could be liberated by the fission (splitting) of the nuclei of a twin of the heaviest element in nature—namely, uranium of atomic mass 235

(235 times the mass of the hydrogen atom, lightest of all the elements)—scientists had known that truly staggering amounts of energy would be released if one could fuse together four atoms of hydrogen, the first element on the atomic table, into one atom of helium, element number two on that table, which weighs about four times as much as hydrogen. In December 1938—three weeks before the discovery of uranium fission was announced in Germany—Dr. Bethe had published his famous hypothesis about the fusion of four hydrogen atoms in the sun to form helium. This provided the first satisfactory explanation of the mechanism that enables the sun to radiate away in space every second a quantity of light and heat equivalent to the energy content of nearly fifteen quadrillion tons of coal. And while Dr. Bethe was the first to work out the fine details of the process, scientists had been speculating for more than twenty years on the likelihood of hydrogen fusion in the sun as source of the sun's eternal radiance.

American audiences first heard about hydrogen as the solar fuel in a lecture, on March 10, 1922, at the Franklin Institute, Philadelphia, by Professor Francis William Aston, famous British Nobel-Prize-winning chemist, who even at that early date warned mankind against what he called "tinkering with the angry atoms." His words on that occasion have a strange prophetic ring, though most of what he said is now known to be wrong. "Should

the research worker of the future discover some means of releasing this energy [from hydrogen] in a form which could be employed," he predicted, "the human race will have at its command powers beyond the dreams of scientific fiction, but the remote possibility must always be considered that the energy, once liberated, will be completely uncontrollable and by its violence detonate a neighboring substance. If this happens, all of the hydrogen on earth might be transformed [into helium] at once, and this most successful experiment might be published to the rest of the universe in the form of a new star of extraordinary brilliance, as the earth blew up in one vast explosion."

By 1945 we had learned that many things were wrong in Professor Aston's prophecy. It had been definitely established, for example, that it would be impossible to "transform all the hydrogen on earth at once," no matter how many superduper hydrogen bombs were to be exploded. In fact, we had learned that, under conditions as they exist on earth, we could never use common hydrogen, the element that makes up one ninth by weight of all water, either in a superduper bomb or as an atomic fuel for power. On the other hand, ten years after Dr. Aston's lecture a new type of hydrogen was discovered to exist in nature. It was found to constitute one five-thousandth part of the earth's waters, including the water in the tissues of plants and animals. It was shown to have an atomic

weight of two—double the weight of common hydrogen—and was named deuterium. The nucleus, or center, of the deuterium atom was named the deuteron, to distinguish it from the nucleus of common hydrogen, known as the proton. Deuterium also became popularly known as "heavy hydrogen." Water containing two deuterium atoms in place of the two atoms of light hydrogen became known as "heavy water."

The most startling fact learned about deuterium soon after its discovery in 1932 was that it offered potentialities as an atomic fuel, or an explosive, of tremendous energy, provided one condition could be met. This condition was a "match" to light it with. And here was the catch. The flame of this match, it was found, would have to have a temperature of the order of 50,000,000 degrees centigrade, two and a half times the temperature in the interior of the sun.

Oddly enough, the discovery of the principle that made the atomic bomb possible also brought with it the promise that a "deuterium fire" might, after all, be lighted on earth. Early studies had revealed that the explosion of an atomic bomb, if it lived up to expectations, would generate a central temperature of about 50,000,000 degrees centigrade. Here, at last, was the promise of realization of the impossible—the 50,000,000 degree match.

The men of Los Alamos thus knew that if the atomic bomb they were just completing for its

first test worked as they hoped it would, it could be used as the match to light the deuterium fire. They could build a superduper bomb of a thousand times the power of the atomic bomb by incorporating deuterium in the A-bomb, the explosion of which would act as the trigger for the superexplosion. And they also knew that the deuterium bomb held such additional potentialities of terror, beyond its vastly greater blasting and burning power, that the step from the duper to the super would be just as great as the step from TNT to the duper.

The hydrogen bomb, H-bomb, or hell bomb, as the fusion bomb had become popularly known, thus became a reality in the flash of the explosion of the first atomic bomb at 5:30 of the morning of July 16, 1945, on the New Mexico desert. As the men of Los Alamos, of whom I was at that time a privileged member, watched the supramundane light and the apocalyptic mushroom-topped mountain of nuclear fire rising to a height of more than eight miles through the clouds, they did not have to wait until they checked with their measuring instruments to know that a match sparking a flame of about 50,000,000 degrees centigrade had been lighted on earth for the first time. The size of the fire mountain and the end-of-the-world-like thunder that reverberated all around, told the tale better than any puny man-made instruments.

And there in our midst, as we learned only re-

cently, stood a Judas, Klaus Fuchs, a name that "will live in infamy" along with that of other arch-traitors of history. By the greatest of ironies, there he was, this spy, standing right in the center of what we believed at the time to be the world's greatest secret, waiting at that very moment to tell the Russians of our success and how we achieved it. As he confessed five years later, he betrayed to them the most intimate details not only about the A-bomb but about the H-bomb as well—details that he learned as a member of the innermost of inner circles. For, alas, he was a trusted member of the theoretical division, the sanctum sanctorum of Los Alamos. This select group of scientists, behind doubly and triply locked doors, discussed in whispers their ideas about the superduper.

His associates at Los Alamos, who should know, sadly admit that Fuchs made it possible for Russia to develop her A-bomb at least a year ahead of time. It is my own conviction that the information he gave the Russians made it possible for their scientists to attain their goal at least three, and possibly as much as ten, years sooner than they could have done it on their own. Yet, though Fuchs confessed everything he told the Russians, the content of his confession is still kept a top secret from the American people, who sadly need information on one of the greatest problems facing mankind. The reason given is that we cannot

actually be sure that Fuchs told the Russians all that he says he did, and, if published, his confession might, by his tricky design, give the Russians additional information. Of course, anything is possible for a warped mind such as that of Fuchs. Nevertheless, it seems highly implausible that this traitor, who went to the Russians voluntarily, should withhold any vital information from them for as long as five years. The best evidence that he didn't is the Russian A-bomb.

Yet some good comes even of the greatest evil. All the circumstantial evidence points to the fact that during the five-year period following the end of the war our work on the hydrogen bomb had stopped completely. The A-bomb was the mightiest weapon in the world, we seem to have reasoned, and it would take Russia many years before she would get an A-bomb of her own. Why spend great efforts on a superbomb?

The shock when Russia exploded her first A-bomb much sooner than we expected, topped by the second shock that Fuchs had handed Moscow all our major secrets on a platter—including, as must be surmised, those of the H-bomb—awakened us to the facts of life. It is no accident that President Truman's official announcement of the order to build "the so-called hydrogen bomb or superbomb" came within three days of the announcement of Fuchs's arrest and confession. The President gave his order with full knowledge of

Fuchs's confession, which made it evident that the Russians were already at work on the hydrogen bomb and had probably been working on it uninterruptedly since 1945. The tragic prospect is that instead of the Russians catching up with us, it is we who may have to catch up with them.

Five years after the first announcement of the explosion of the A-bomb over Hiroshima, even the most intelligent Americans still have only the vaguest idea about the facts. Yet these facts are within the understanding of the average man. If we keep the earlier analogy of the match in mind, it becomes simple to understand the principles underlying both the A-bomb, now more correctly identified as the "fission bomb," and the hydrogen bomb, more properly described as the "fusion bomb."

Our principal fuel is coal, which, as everyone knows, is "bottled sunshine," stored up in plants that grew about two hundred million years ago. When we apply the small amount of heat energy from a match, the bottled energy is released in the form of light and heat, which we can use in a great variety of ways. The point here is that it requires only the application of a very small amount of energy from a match to release a very large amount of energy that has been stored for millions of years in the ancient plants we know as coal.

Now, during the past half century we discovered that the nuclei, or centers, of the smallest

units of which the ninety-odd elements of the material universe are made up—units we know as atoms—had stored up within them since the beginning of creation amounts of energy millions of times greater than is stored up by the sun in coal. But we had no match with which to start an atomic fire burning.

Then, in January 1939, came the world-shaking discovery of the phenomenon known as uranium fission. In simple language, we had found a proper "match" for lighting a fire with a twin of uranium, the ninety-second, and last, natural element. This twin is a rare form of uranium known as uranium 235—the figure signifying that it is 235 times heavier than common hydrogen. Doubly phenomenal, the discovery of uranium fission meant that to light the atomic fire, with the release of stored-up energy three million times greater than that of coal and twenty million times that of TNT (on an equal-weight basis) would require no match at all. When proper conditions are met, the atomic fire would be lighted automatically by spontaneous combustion.

What are these proper conditions? In the presence of certain chemical agencies, spontaneous combustion will take place when an easily burning substance, such as sawdust, for example, accumulates heat until it reaches the kindling temperature at which it ignites. The chemical agencies here are the equivalent of a match.

The requirement to start the spontaneous combustion of uranium 235, and also of two man-made elements named plutonium and uranium 233 (all three known as fissionable materials or nuclear fuels), is just as simple. In this operation you do not need a critical temperature, but what is known as a critical mass. This simply means that spontaneous combustion of any one of the three atomic fuels takes place as soon as you assemble a lump of a certain weight. The actual critical mass is a top secret. But the noted British physicist, Dr. M. L. E. Oliphant, of radar fame, published in 1946 his own estimate, which places its weight between ten and thirty kilograms. If so, this would mean that a lump of uranium 235 (U-235), plutonium, or U-233, weighing ten or thirty kilograms, as the case may be, would explode automatically by spontaneous combustion and release an explosive force of 20,000 tons of TNT for each kilogram undergoing complete combustion. In the conventional A-bomb a critical mass is assembled in the last split second by a timing mechanism that brings together, let us say, one tenth and nine tenths of a critical mass. The spontaneous combustion that followed such a consummation on August 6 and 9, 1945 destroyed Hiroshima and Nagasaki.

Thus, if we substitute the familiar phrase "spontaneous combustion" for the less familiar word "fission," we get a clear understanding of what is

known in scientific jargon as the "fission process," a "self-multiplying chain reaction with neutrons," and similar technical mumbo-jumbo. These terms simply mean the lighting of an atomic fire and the release of great amounts of the energy stored in the nuclei of U-235 since the beginning of the universe. The two so-called man-made elements are not really created. They are merely transformed out of two natural heavy elements in such a way that their stored energy is liberated by the process of spontaneous combustion.

Why, one may ask, does not spontaneous combustion of U-235 take place in nature? Why, indeed, has not all the U-235 in nature caught fire automatically long ago? To this also there is a simple answer. Just as in the spontaneous combustion of sawdust the material must be dry enough to burn, so must the U-235. Only in place of the word "dry" we must use the word "concentrated." The U-235 found in nature is very much diluted with another element that makes it "wet." It therefore must be separated first, by a very laborious and costly process, from the nonfissionable, or "wetting," element. Even then it won't catch fire, and could not be made to burn by any means, until the amount separated ("dried") reaches the critical mass. When these two conditions—conditions that do not exist in nature—are met, the U-235 catches fire just as sawdust does when it reaches the critical temperature.

The fact that as soon as a critical mass is assembled the three elemental atomic fuels burst into flame automatically thus puts a definite limit to the amount of material that can be used in the conventional A-bomb. The best you can do is to incorporate into a bomb two fragments, let us say, of nine tenths of a critical mass each. To enclose more than two such fragments would present difficulties that appear impossible to overcome. It is this limitation of size, an insurmountable roadblock put there by mother nature, that makes the basic difference between the A-bomb and the H-bomb.

For, as we have already seen, to light an atomic fire with deuterium it is necessary to strike a match generating a flame with a temperature of about 50,000,000 degrees centigrade. As long as no such match is applied, no fire can start. It thus becomes obvious that deuterium is not limited by nature to a critical mass. A quantity of deuterium a thousand times the amount of the U-235, and hence a thousand times more powerful, can therefore be incorporated in an ordinary A-bomb, where it would remain quiescent until the A-bomb match is struck. Weight for weight, deuterium has only a little more energy content than U-235, so that a bomb incorporating a 1,000 kilograms (one ton) of deuterium would thus have an energy of 20,000,000 tons of TNT.

Here must be mentioned another form of hydrogen, named tritium. It has long ago disappeared

from nature but it is now being re-created in ponderable amounts in our atomic furnaces. Tritium, the nucleus of which is known as a triton, weighs three times as much as the lightest form of hydrogen. It has an energy content nearly twice that of deuterium. But it is very difficult to make and is extremely expensive. Its cost per kilogram at present AEC prices is close to a billion dollars, as compared with no more than $4,500 for a kilogram of deuterium. A combination of deuterons and tritons would release the greatest energy of all, 3.5 times the energy of deuterons alone. It would reduce the amount of tritons required to half the volume and three fifths of the weight required in a pure triton bomb, thus making the cost considerably lower.

But why bother with such fantastically costly tritons when we can get all the deuterium we want at no more than $4,500 a kilogram, while we can make up the difference in energy by merely incorporating two to three and a half times as much deuterium? Here we are dealing with what is probably the most ticklish question in the design of the H-bomb.

To light a fire successfully, it is not enough merely to have a match. The match must burn for a time long enough for its flame to act. If you try to light a cigarette in a strong wind, the wind may blow out your match so fast that your cigarette will not light. The same question presents it-

self here, but on a much greater scale. The match for lighting deuterium—namely, the A-bomb—burns only for about a hundred billionths of a second. Is this time long enough to light the "cigarette" with this one and only "match"?

It is known that the time is much too slow for lighting deuterium in its gaseous form. But it is also known that the inflammability is much faster when the gas is compressed to its liquid form, at which its density is 790 times greater. At this density it would take only seven liters (about 7.4 quarts) per one kilogram (2.2 pounds), as compared with 5,555 liters for gaseous deuterium. And it catches fire in a much shorter time.

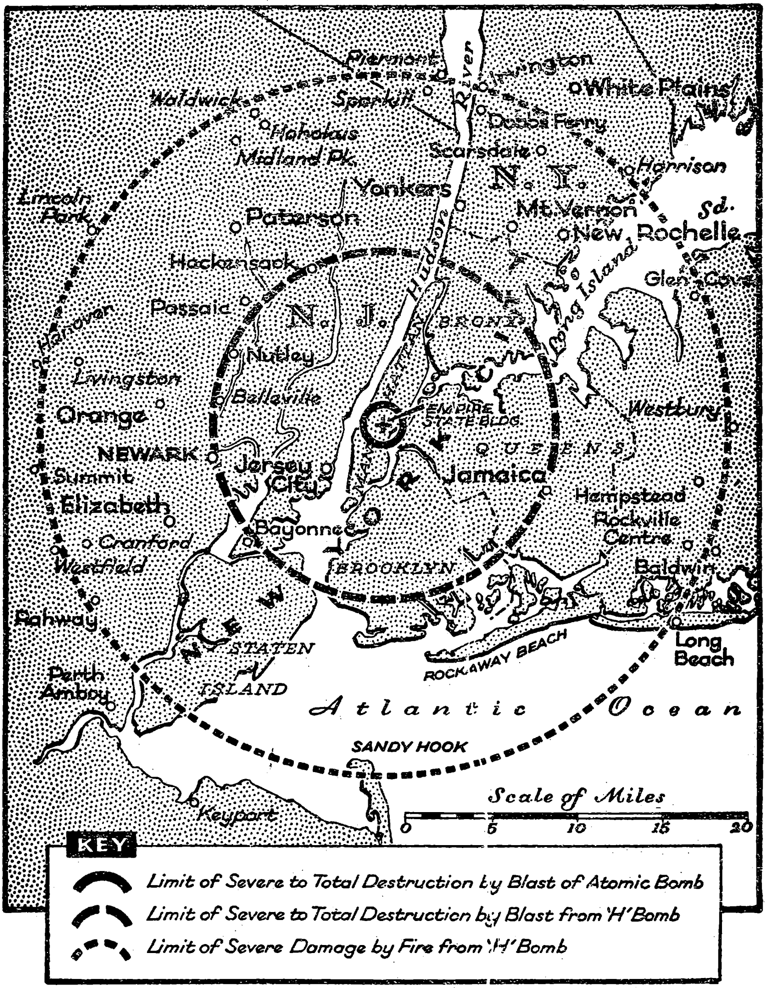
Is this time long enough? On the answer to this question will depend whether the hydrogen bomb will consist of deuterium alone or of deuterium and tritium, for it is known that the deuteron-triton combination catches fire much faster than deuterons or tritons alone.

We were already working with tritium in Los Alamos as far back as 1945. I remember the time when Dr. Oppenheimer, wartime scientific director of Los Alamos, went to a large safe and brought out a small vial of a clear liquid that looked like water. It was the first highly diluted minute sample of superheavy water, composed of tritium and oxygen, ever to exist in the world, or anywhere in the universe, for that matter. We both looked at it in silent, rapt admiration. Though we did not

speak, each of us knew what the other was thinking. Here was something, our thoughts ran, that existed on earth in gaseous form some two billion years ago, long before there were any waters or any forms of life. Here was something with the power to return the earth to its lifeless state of two billion years ago.

The question of what type of hydrogen is to be used in the H-bomb therefore hangs on the question of which one of the possible combinations will catch fire by the light of a match that is blown out after an interval of about a hundred billionths of a second. On the answer to this question will also depend the time it will take us to complete the H-bomb and its cost. To make a bomb of a thousand times the power of the A-bomb would require a 1,000 kilograms of deuterium at a cost of $4,500,000, or 171 kilograms of tritium and 114 kilograms of deuterium at a total cost of more than $166,000,000,000 at current prices, not counting the cost of the A-bomb trigger. Large-scale production of tritium, however, will most certainly reduce its cost enormously, possibly by a factor of ten thousand or more, while, as will be indicated later, the amount of tritium, if required, may turn out to be much smaller.

We can thus see that if deuterium alone is found to be all that is required to set off an H-bomb it will be cheap and relatively easy to make in a short time—both for us and for Russia. Further-



MAP BY DANIEL BROWNSTEIN

more, such a deuterium bomb would be practically limitless in size. One of a million times the power of the Hiroshima bomb is possible, since deuterium can be extracted in limitless amounts from plain water. On the other hand, if sizable amounts of tritium are found necessary, the cost will be much higher and it will take a considerably longer time, since the production of tritium is very slow and costly. This, in turn, will place a definite limit on the power of the H-bomb, since, unlike deuterium, the amounts of tritium will necessarily always be limited. As will be shown later, we are at present in a much more advantageous position to produce tritium than is Russia, so that if tritium is found necessary, we have a head start on her in H-bomb development.

The radius of destructiveness by the blast of a bomb with a thousand times the energy of the A-bomb will be only ten times greater, since the increase goes by the cube root of the energy. The radius of total destruction by blast in Hiroshima was one mile. Therefore the radius of a superbomb a thousand times more powerful will be ten miles, or a total area of 314 square miles. A bomb a million times the power of the Hiroshima bomb would require 1,000 tons of deuterium. Such a super-superduper could be exploded at a distance from an abandoned, innocent-looking tramp ship. It would have a radius of destruction by blast of 100 miles and a destructive area of more than 30,-

000 square miles. The time may come when we shall have to search every vessel several hundred miles off shore. And the time may be nearer than we think.

The radius over which the tremendous heat generated by a bomb of a thousandfold the energy would produce fatal burns would be as far as twenty miles from the center of the explosion. This radius increases as the square root, instead of the cube root, of the power. The Hiroshima bomb caused fatal burns at a radius of two thirds of a mile.

The effects of the radiations from a hydrogen bomb are so terrifying that by describing them I run the risk of being branded a fearmonger. Yet facts are facts, and they have been known to scientists for a long time. It would be a disservice to the people if the facts were further denied to them. We have already paid too high a price for a secrecy that now turns out never to have been secret at all.

I can do no better than quote Albert Einstein. "The hydrogen bomb," he said, "appears on the public horizon as a probably attainable goal. . . . If successful, radioactive poisoning of the atmosphere, and hence annihilation of any life on earth, has been brought within the range of technical possibilities."

What Dr. Einstein meant by "radioactive poisoning of the atmosphere, and hence the annihilation

of any life on earth," was explained in realistic detail by such eminent physicists as Dr. Bethe, Dr. Leo Szilard, Dr. Edward Teller, and others. All of them may even now be engaged on work on the hydrogen bomb.

Here is how "poisoning of the atmosphere" may result from the explosion of a hydrogen bomb: Tremendous quantities of neutrons, which can enter any substance in nature and make it radioactive, are liberated. In the case of a deuterium bomb, one eighth of the mass used—125 grams per kilogram—is liberated. In the case of a deuteron-tritium bomb, fully one fifth of the mass—200 grams per kilogram—is released, while in a bomb using pure tritium, fully one third of the mass—333 grams per kilogram—is liberated as free neutrons. There are 600,000 billion billion neutrons in each gram, each capable of producing a radioactive atom in its environment. The neutron is one of the two building blocks of the nuclei of all atoms.

These neutrons can be used to make any element radioactive, Professor Szilard and his colleagues point out. It follows that the casing of the bomb could be selected with a view to producing, after the neutrons enter it, an especially powerful radioactive substance. Since each artificially made, radioactive element gives out a specific type of radiation and has a definite life span, after which it decays to one half of its radioactivity, the de-

signer of the bomb could rig it in such a way that its explosion would spread into the air a tremendous cloud of specially selected radioactive substances that would give off lethal radiations for a definite period of time. In such a way a large area could be made unfit for human or animal habitation for a definite period of time, months or years.

Take, for example, the very common element cobalt. When bombarded with neutrons, it turns into an intensely radioactive element, 320 times more powerful than radium. Any given quantity of neutrons would produce sixty times its weight in radioactive cobalt. If the bomb contains a ton of deuterium, 250 pounds would come out as neutrons. On the assumption that every neutron enters a cobalt atom, this would produce 7.5 tons of radioactive cobalt. That quantity would give out as much radioactivity as 2,400 tons of radium.

Now, this radioactive cobalt has a half-life of five years, meaning that it loses half of its radioactive power at every five-year period. So after a lapse of that period of time its radioactivity would be equal to 1,200 tons of radium, in ten years to 600 tons, and so on. If used as a bomb-casing it would be pulverized and converted into a gigantic radioactive cloud that would kill everything in the area it blankets. Nor would it be confined to a particular area, since the winds would take it thousands of miles, carrying death to distant places.

The radioactivity produced by the Bikini bombs was detected within one week in the United States. In that short time the westerly winds swept the radioactive air mass from Bikini, 4,150 miles away, to San Francisco. When it reached our shores, the activity was weak and completely harmless, but it was still detectable. That, by the way, was how we learned that the Russians had exploded their first atomic bomb.

But, in the words of Professor Teller, one of the Los Alamos men who made the preliminary studies on the hydrogen bomb, "if the activity liberated at Bikini were multiplied by a factor of a hundred thousand or a million, and if it were to be released off our Pacific Coast, the whole of the United States would be endangered." He added that "if such a quantity of radioactivity should become available, an enemy could make life hard or even impossible for us without delivering a single bomb into our territory."

One limitation to such an attack, Professor Teller points out, is the boomerang effect of these gases on the attacker himself. The radioactive gases would eventually drift over his own country, too. He adds, however, that since these gases have different rates of decay—some faster, some slower—the attacker is in a position to choose those radioactive products best suited to his attack. "With the proper choice he could ensure that his victim would be seriously damaged by them, and

that they would have decayed by the time they reached his own country."

"It is not even impossible to imagine," in the words of Professor Teller, "that the effects of an atomic war fought with greatly perfected weapons and pushed by utmost determination will endanger the survival of man. . . . This specific possibility of destruction may help us realize more clearly the probable consequences of an atomic war for our civilization and the possible consequences for the whole human race."

On this point Professor Szilard is much more specific. "Let us assume," he said at a University of Chicago Round Table, "that we make a radioactive element which will live for five years and that we just let it go into the air. During the following years it will gradually settle out and cover the whole earth with dust. I have asked myself, 'How many neutrons or how much heavy hydrogen do we have to detonate to kill everybody on earth by this particular method?' I come up with about fifty tons of neutrons as being plenty to kill everybody, which means about 400 tons of heavy hydrogen" (deuterium).

Now, obviously Professor Szilard was stating the extreme case. He merely called attention to the scientific fact that man now has at his disposal, or soon will have, means that not only could wipe out all life on earth, but could also make the earth itself unfit for life for many generations to come,

if not forever. Here we have indeed what is probably the greatest example of irony in man's history. The very process in the sun that made life possible on earth, and is responsible for its being maintained here, can now be used by man to wipe out that very life and to ruin the earth for good.

It is inconceivable that any leaders of men today, or in the near future, would resort to such an extreme measure. But the fact remains that such a measure is possible. And it is by no means unthinkable that a Hitler, faced with certain defeat, would not choose to die in a great Götterdämmerung in which he would pull down the whole of humanity with him to destruction. And who can be bold enough to guarantee that another Hitler might not arise sometime, somewhere, possibly in a rejuvenated Germany making another bid for world domination or total annihilation?

It is more likely, of course, that an attacker, particularly if he is otherwise faced with certain defeat, might choose the less drastic method outlined by Professor Teller, selecting for his weapon a short-lived radioactive element that would have spent itself by the time it reached his shores. If he is the sole possessor of the hydrogen bomb, he may not even have to use it, a threat of its use being sufficient to end the war on terms to his liking. In the face of such a threat, as Professor Szilard pointed out, who would dare take the responsibility of refusing?

These are the stark, unvarnished facts about the "so-called hydrogen bomb." They raise many questions to which the American people as a whole will have to find the answer. It is possible, and the odds here are more than even, that the very possession of the hydrogen bomb by both ourselves and Russia will make war unthinkable, since neither side could be the winner. This would be a near certainty if we had the answer to Russia's Trojan Horse method of taking over nations by first taking over their governments, as was done in Poland, Czechoslovakia, Hungary, and the Balkan countries. Suppose the Communists take over Italy, then Germany, by the same method. What would we do then? The answer is, of course, that if we wait until "then," everything would be lost, no matter what we did. It therefore becomes obvious that our very existence may depend on what we do *here* and *now* to prevent such an eventuality.

Now that the hydrogen bomb has come out into the open after five years as a super-top secret, the authorities, and particularly the Atomic Energy Commission, may be called upon to answer some embarrassing questions. "Why," we may ask, "was the work on the hydrogen bomb apparently dropped altogether during the past five years?" According to Professor Bethe, it would take about three years to develop it. This means that, had we

continued working on it in 1945 and thereafter, we we would have had it as far back as 1948. We have thus lost five precious years, our loss being Russia's gain.

Some scientists and others contend that, because of our great harbor and industrial cities, the hydrogen bomb would be a greater threat to us than to the Soviet, because most Russian cities are much smaller than ours, while her industries are much more dispersed. There may be some truth in this. But on the other hand there are some great advantages on our side. With a strong Navy and good submarine-detecting devices we may have control of the seas and be able to prevent the delivery of the hydrogen bomb by ship or submarine. With a strong Air Force and radar system we could prevent the delivery of hydrogen bombs from the air.

By far the most important advantage the possession of the hydrogen bomb would give us against Russia is its possible use as a tactical weapon against huge land armies. Since they can devastate such large areas, one or two hydrogen bombs, depending on their size, could wipe out entire armies on the march, even before they succeeded in crossing the border of an intended victim. The H-bomb would thus counterbalance, if not completely nullify, the one great advantage Russia possesses—huge land armies capable of overrunning western Europe. The bomb might thus serve

as the final deterrent to any temptation the Kremlin's rulers may have to invade the Atlantic Pact countries.

Yet no matter how one looks at it, the advent of the H-bomb constitutes the greatest threat to the survival of the human race since the Black Death.

One is reminded of a dinner conversation in Paris in 1869, recorded in the *Journal* of the Goncourt brothers. Some of the famous savants of the day were crystal-gazing into the scientific future a hundred years away. The great chemist Pierre Berthelot predicted that by 1969 "man would know of what the atom is constituted and would be able, at will, to moderate, extinguish, and light up the sun as if it were a gas lamp." (This prophecy has almost come true.) Claude Bernard, the greatest physiologist of the day, saw a future in which "man would be so completely the master of organic law that he would create life [artificially] in competition with God."

To which the Goncourt brothers added the postscript: "To all of this we raised no objection. But we have the feeling that when this time comes to science, God with His white beard will come down to earth, swinging a bunch of keys, and will say to humanity, the way they say at five o'clock at the salon: 'Closing time, gentlemen!' "

II

THE REAL SECRET OF THE HYDROGEN BOMB

CAN the hydrogen bomb actually be made? If so, how soon? How much will it cost in money and vital materials? Above all, will it, if made, add enough to our security to make the effort worth while?

As was pointed out by Prof. Robert F. Bacher of the California Institute of Technology, one of the chief architects of the wartime atomic bomb and the first scientific member of the Atomic Energy Commission, "since the President has directed the AEC to continue with the development ['of the so-called hydrogen, or super bomb'] we can assume that this development is regarded as both possible and feasible." Many eminent physicists believe that it can be made, and the use by the President of the word "continue" suggests that this belief is based on more than theory. No less an authority than Albert Einstein has stated publicly that he regards the H-bomb as "a probably attainable goal."

On the other hand, there are scientists of high eminence, such as Dr. Robert A. Millikan, our oldest living Nobel-Prize-winner in physics, who doubt whether the H-bomb can be made at all. And there are also those who express the view

that, while it probably could be made, it would not offer advantages great enough, if any, to justify the cost in vital strategic materials necessary for our security.

Fortunately, facts mostly buried in technical literature make it possible for us to go behind the scientific curtain and look intimately at the reasons for these differences in opinion. More important still, these facts not only provide us with a clearer picture of the nature of the problem but also enable us to make some reasonable deductions or speculations. The scientists directly involved do not feel free to discuss these matters openly, not because they would be violating security, but because of the jittery atmosphere that acts as a damper on open discussion even of subjects known to be non-secret.

We already know that the so-called hydrogen bomb, if it is to be made at all, cannot be made of the abundant common hydrogen of atomic mass one, and that there are only two possible materials that could be used for such a purpose: deuterium, a hydrogen twin twice the weight of common hydrogen, which constitutes two hundredths of one per cent of the hydrogen in all waters; and a man-made variety of hydrogen, three times the weight of the lightest variety, known as tritium. We also know that to explode either deuterium or tritium (also known, respectively, as heavy and super-heavy hydrogen) a temperature measured in mil-

lions of degrees is required. This is attainable on earth only in the explosion of an A-bomb, and therefore the A-bomb would have to serve as the fuse to set off an explosion of deuterium, tritium, or a mixture of the two.

These facts, fundamental as they are, merely give us a general idea of the conditions required to make the H-bomb. All concerned, including Dr. Millikan, fully accept the validity of these facts. But there is one other factor at the very heart of the problem—the extremely short time at our disposal in which to kindle the hydrogen bomb with the A-bomb match. According to statements attributed to him in the press, Dr. Millikan believes that the time is too short; in other words, he seems to be convinced that the A-bomb match will be blown out before we have time to light the fire. Those of opposite view believe that methods can be devised for "shielding the match against the wind" for just long enough to light the fire. As we shall presently see, it is these methods for shielding the match that lead some to doubt whether the game would be worth the candle, or the match, if you will. These honest doubts are based on the possibility that, even if successful, the shielding might exact too high a price in terms of vital materials, particularly the stuff out of which A-bombs are made—plutonium. According to this view, we may at best be getting but a very small return for our investment in materials vitally important in

war as well as in peace. Even though the price in dollars were to be brought down to a negligible amount.

A closer look at the details of the problem may enable us to penetrate the thick fog that now envelops the subject. We may begin with a quotation from Dr. Bacher, who outlined the principle involved with remarkable clarity. "The real problem in developing and constructing a hydrogen bomb," he said in a notable address before the Los Angeles Town Hall,

is, "How do you get it going?" The heavy hydrogens, deuterium and tritium, are suitable substances if somehow they could be heated hot enough and kept hot. This problem is a little bit like the job of making a fire at 20 degrees below zero in the mountains with green wood which is covered with ice and with very little kindling. Today, scientists tell us that such a fire can probably be kindled.

Once you get the fire going, of course, you can pile on the wood and make a very sizeable conflagration. In the same way with the hydrogen bomb, more heavy hydrogen can be used and a bigger explosion obtained. It has been called an open-ended weapon, meaning that more materials can be added and a bigger explosion obtained.

The phrase that goes to the very heart of the problem is "very little kindling," which is another way of illustrating the difficulty of lighting a fire in a high wind when you have only one match. We

know that to ignite deuterium, by far the cheaper and more abundant of the two H-bomb elements, a temperature comparable to those existing in the interior of the sun, some 20,000,000 degrees centigrade, is necessary. This temperature can be realized on earth only in the explosion of an A-bomb. We also know that the wartime model A-bombs generated a temperature of about 50,000,000 degrees, more than enough to light a deuterium fire. The trouble lies in the extremely short time interval, of the order of a millionth of a second (microsecond), and a fraction thereof, during which the A-bomb is held together before it flies apart. In the words of Professor Bacher, we must make our green, ice-covered wood catch fire in the subzero mountain weather before the "very little kindling" we have is burned up.

The times at which deuterium will ignite at any given temperature, in both its gaseous and its liquid form, are widely known among nuclear scientists everywhere, including Russia, through publication in official scientific literature of a well-known formula, originally worked out by two European scientists as far back as 1929, and more recently improved upon by Professor George Gamow and Professor Teller. By this formula, derived from actual experiments, it is known that deuterium in its gaseous form will require as long as 128 seconds to ignite at a temperature of 50,000,000 degrees centigrade, well above 100,000,-

000 times longer than the time in which our little kindling is used up. This obviously rules out deuterium in its natural gaseous form as material for an H-bomb.

How about liquid deuterium? We know that the more atoms there are per unit volume (namely, the greater the density), the faster is the time of the reaction. The increase in the speed of the reaction (in this case the ignition of the deuterium) is directly proportional to the square of the density. For example, if the density, (that is, the number of atoms per unit volume) is increased by a factor of 10, the time of ignition will be speeded up by the square of 10, or 100 times faster. Since liquid deuterium has a density nearly 800 times that of gaseous deuterium, this means that liquid deuterium (which must be maintained at a temperature of 423 degrees below zero Fahrenheit at a pressure above one atmosphere) would ignite 640,000 times faster (namely, in 1/640,000th part of the time) than its gaseous form. Arithmetic shows that the ignition time for liquid deuterium at 50,000,000 degrees centigrade will be 200 microseconds, still 200 times longer than the period in which our kindling is consumed.

The same formula also reveals the time it would take liquid deuterium to ignite at higher temperatures, the increase of which shortens the ignition time. These figures show that the ignition time for liquid deuterium at 75,000,000 degrees centigrade

is 40 microseconds. At 100,000,000 degrees the time is 30 microseconds; at 150,000,000 degrees, 15 microseconds; and at 200,000,000 degrees on the centigrade scale, about 4.8 millionths of a second. Doubling the temperature speeds up the ignition time for liquid deuterium by a factor of about six.

The problem thus is a dual one: to raise the temperature at which the A-bomb explodes, and to extend the time before the A-bomb flies apart. It is also obvious that if the liquid deuterium is to be ignited at all, it must be done before the bomb has disintegrated—that is, during the incredibly short time interval before it expands into a cloud of vapor and gas, since by then the deuterium would no longer be liquid.

Can we increase the A-bomb's temperature fourfold to 200,000,000 degrees and literally make time stand still while it holds together for nearly five millionths of a second? To get a better understanding of the problem we must take a closer look at what takes place inside the A-bomb during the infinitesimal interval in which it comes to life.

This life history of the A-bomb is an incredible tale, from the time its inner mechanisms are set in motion until its metamorphosis into a great ball of fire. As explained earlier, the A-bomb's explosion takes place through a process akin to spontaneous combustion as soon as a certain minimum amount (critical mass) of either one of two fissionable

(combustible) elements—uranium 235 or plutonium—is assembled in one unit. The most obvious way it takes place is by bringing together two pieces of uranium 235 (U-235), or plutonium, each less than a critical mass, firing one of these into the other with a gun mechanism, thus creating a critical mass at the last minute. If, for example, the critical mass at which spontaneous combustion takes place is ten kilograms (the actual figure is a top secret), then the firing of a piece of one kilogram into another of nine kilograms would bring together a critical mass that would explode faster than the eye could wink—in fact, some thousands of times faster than TNT.

Just as an ordinary fire needs oxygen, so does an atomic fire require the tremendously powerful atomic particles known as neutrons. Unlike oxygen, however, neutrons do not exist in a free state in nature. Their habitat is the nuclei, or hearts, of the atoms. How, then, does the spontaneous combustion of the critical mass of U-235 or plutonium begin? All we need is a single neutron to start things going, and this one neutron may be supplied in one of several ways. It can come from the nucleus of an atom in the atmosphere, or inside the bomb, shattered by a powerful cosmic ray that comes from outside the earth. Or the emanation from some radioactive element in the atmosphere, or from one introduced into the body of the bomb, may split the first U-235 or plutonium atom, knock

out two neutrons, and thus start a chain reaction of self-multiplying neutrons.

To understand the chain reaction requires only a little arithmetic. The first atom split releases, on the average, two neutrons, which split two atoms, which release four neutrons, which split four atoms, which release eight neutrons, and so on, in a geometric progression that, as can be seen, doubles itself at each successive step. Arithmetic shows that anything that is multiplied by two at every step will reach a 1,000 (in round numbers) in the first ten steps, and will multiply itself by a 1,000 at every ten steps thereafter, reaching a million in twenty steps, a billion in thirty, a trillion in forty, and so on. It can thus be seen that after seventy generations of self-multiplying neutrons the astronomical figure of two billion trillion (2 followed by 21 zeros) atoms have been split.

At this point let us hold our breath and get set to believe what at first glance may appear to be unbelievable. The time it takes to split these two billion trillion atoms is no more than one millionth of a second (one microsecond). If we keep this time element in mind we can arrive at a clear understanding of the tremendous problem involved in exploding an A- or an H-bomb.

And while we are recovering from the first shock we may as well get set for another. That unimaginable figure of two billion trillion atoms represents the splitting (explosion) of no more than one

gram (1/28th of an ounce) of U-235, or plutonium.

Now, the energy released in the splitting of one gram of U-235 is equivalent in power to the explosive force of 20 tons of TNT, or two old-fashioned blockbusters. Since we know from President Truman's announcement following the bombing of Hiroshima that the wartime A-bomb "had more power than 20,000 tons of TNT," it means that the atoms in an entire kilogram (1,000 grams) of U-235 or plutonium must have been split. In other words, after the A-bomb had reached a power of 20 tons of TNT, it had to be kept together long enough to increase its power a thousandfold to 20,000 tons. This, as we have seen, requires only ten more steps. It can also be seen that it is these ten final crucial steps that make all the difference between a bomb equal to only two blockbusters, which would have been a most miserable two-billion-dollar fiasco, and an atomic bomb equal in power to two thousand blockbusters.

With the aid of these facts we are at last in a position to grasp the enormousness of the problem that confronted our A-bomb designers at Los Alamos and is confronting them again today. It can be seen that for a bomb to multiply itself from 20 to 20,000 tons in ten steps by doubling its power at every step, it has to pass successively the stages of 40, 80, 160, 320, and so on, until it reaches an explosive power of 2,500 tons at the seventh step. Yet it still has to be held together for three more

steps, during which it reaches the enormous power of 5,000 and 10,000 tons of TNT, without exploding.

Here was an irresistible force, and the problem was to surround it with an immovable body, or at least a body that would remain immovable long enough for the chain reaction to take just ten additional steps following the first seventy. There is only one fact of nature that makes this possible, or even thinkable—the last ten steps from 20 to 20,000 tons take only one tenth of a millionth of a second. The problem thus was to find a body that would remain immovable against an irresistible force for no longer than one tenth of a microsecond, 100 billionths of a second.

This immovable body is known technically as a "tamper," which pits inertia against an irresistible force that builds up in 100 billionths of a second from an explosive power of 20 tons of TNT to 20,000 tons. The very inertia of the tamper delays the expansion of the active substance and makes for a longer-lasting, more energetic, and more efficient explosion. The tamper, which also serves as a reflector of neutrons, must be a material of very high density. Since gold has the fifth highest density of all the elements (next only to osmium, iridium, platinum, and rhenium), at one time the use of part of our huge gold hoard at Fort Knox was seriously considered.

With these facts and figures in mind, it becomes

clear that an H-bomb made of deuterium alone is not feasible. It is certainly out of the question with an A-bomb of the Hiroshima or Nagasaki types, which generate a temperature of about 50,000,000 degrees, since, as we have seen, it would take fully 200 microseconds to ignite it at that temperature. It is one thing to devise a tamper that would hold back a force of 20 tons for 100 billionths of a second, and thus allow it to build up to 20,000 tons. It is quite another matter to devise an immovable body that would hold back an irresistible force of 20,000 tons for a time interval 2,000 times larger, particularly if one remembers that in another tenth of a microsecond the irresistible force would increase again by 1,000 to 20,000,000 tons. Obviously this is impossible, for if it were possible we would have a superbomb without any need for hydrogen of any kind.

It is known that we have developed a much more efficient A-bomb, which, as Senator Edwin C. Johnson of Colorado has inadvertently blurted out, "has six times the effectiveness of the bomb that was dropped over Nagasaki." We are further informed by Dr. Bacher that "significant improvements" in atomic bombs since the war "have resulted in more powerful bombs and in a more efficient use of the valuable fissionable material." It is conceivable and even probable that the improvements, among other things, include better tampers that delay the new A-bombs long enough

to fission two, four, or even eight times as many atoms as in the wartime models. But since, as we have seen, the ten steps of the final stages require only an average of 10 billionths of a second per step, increasing the power of the new models even to 160,000 tons (eight times the power of the Hiroshima type) would take only three steps, in an elapsed time of no more than 30 billionths of a second. And even if we assume that the improved bomb generates a temperature of 200,000,000 degrees, it would still be too cold to ignite the deuterium during the interval of its brief existence, since, as we have seen, it would take 4.8 microseconds to ignite it at that temperature. In fact, calculations indicate that it would require a temperature in the neighborhood of 400,000,000 degrees to ignite deuterium in the time interval during which the assembly of the improved A-bomb appears to be held together, which, as may be surmised from the known data, is within the range of 1.2 microseconds.

From all this it may be concluded with practical certainty that an H-bomb of deuterium only is out of the question. Equally good, though entirely different, reasons also rule out an H-bomb using only tritium as its explosive element.

There are several important reasons why an H-bomb made of tritium alone is not feasible. The most important by far, which alone excludes it from any serious consideration, is the staggering

cost we would have to pay in terms of priceless A-bomb material, as each kilogram of tritium produced would exact the sacrifice of eighty times that amount in plutonium. The reason for this is simple. Both plutonium and tritium have to be created with the neutrons released in the splitting of U-235, each atom of plutonium and each atom of tritium made requiring one neutron. Since an atom of plutonium has a weight of 239 atomic mass units, whereas an atom of tritium has an atomic weight of only three, it can be seen that a kilogram, or any given weight, of tritium would contain eighty times as many atoms as a corresponding weight of plutonium, and hence would require eighty times as many neutrons to produce. In other words, we would be buying each kilogram of tritium at a sacrifice of eighty kilograms of plutonium, which, of course, would mean a considerable reduction in our potential stockpile of plutonium bombs.

We would cut this loss by more than half because a kilogram of tritium would yield about two and a half times the explosive power of plutonium. But even this advantage would soon be lost, since tritium decays at the rate of fifty per cent every twelve years, so that a kilogram produced in 1951 would decay to only half a kilogram by 1963. Plutonium, on the other hand, can be stored indefinitely without any significant loss, since it changes

slowly (at the rate of fifty per cent every twenty-five thousand years) into the other fissionable element, U-235, which in turn decays to one half in no less than nine hundred million years. What is more, plutonium, if the day comes when we can beat our swords into plowshares, will become one of the most valuable fuels for industrial power, the propulsion of ships, globe-circling airplanes, and even, someday, interplanetary rockets. It holds enormous potentialities as one of the major power sources of the twenty-first century. Tritium, on the other hand, can be used only as an agent of terrible destruction. It will yield its energy in a fraction of a millionth of a second or not at all. The only other possible uses it may have would be as a research tool for probing the structure of the atom, and as a potential new agent in medicine, in which it may be used for its radiations.

How much tritium would it take to make an H-bomb 1,000 times the power of the wartime-model A-bombs? Since tritium has about 2.5 times the power per given weight of U-235 or plutonium, it would take 400 kilograms (about 1,880 quarts of the liquid form) of tritium to make a bomb that would equal the power of 1,000 kilograms of plutonium. Such a bomb, we can see, would have to be made at the sacrifice of 32,000 kilograms of plutonium. In other words, we would be getting a return, in terms of energy content, of

1,000 kilograms for an investment of 32,000. And we would be losing fully half of even this small return every twelve years.

How many A-bombs would we be sacrificing through this investment? On the basis of Professor Oliphant's estimate that the critical mass of an A-bomb is between 10 and 30 kilograms, we would sacrifice at least 1,066, and possibly as many as 3,200, if we take the lower figure. And we must not forget that a bomb a thousand times the power will produce only ten times the destructiveness by blast and thirty times the damage by fire of an A-bomb of the old-fashioned variety.

These cold facts make it clear that a tritium bomb, particularly one a thousand times the power of the A-bomb, is completely out of the picture.

But, one may ask, if a deuterium bomb is not possible and a tritium bomb is not feasible, and these are the only two substances that can possibly be used at all, isn't all this talk about a superbomb sheer moonshine? And if so, how explain President Truman's directive "to continue" work on it?

To find the answer let us go back for a moment to Dr. Bacher's man in the mountains, confronted with the problem of lighting a fire with green, ice-covered wood at twenty degrees below zero with "very little kindling." Obviously the poor fellow would be doomed to freeze to death were it not for one little item he had almost forgotten. Somewhere in his belongings he discovers a container

filled with gasoline, which increases the inflammability of the wet wood to the point at which it will catch fire with a quantity of kindling that would otherwise be much too small.

Something closely analogous is true with the H-bomb. It so happens that a mixture of deuterium and tritium is the most highly inflammable atomic fuel on earth. It yields 3.5 times the energy of deuterium and about twice the energy of tritium when they are burned individually. Most important of all, the deuterium-tritium mixture, known as D-T, ignites much faster than either deuterium or tritium by themselves. For example, the D-T combination ignites 25 times faster than deuterium alone at a temperature of 100,000,000 degrees, and the ignition time is fully 37.5 times faster than for deuterium at 150,000,000 degrees.

The published technical data show that at a temperature of 50 million degrees the D-T mixture ignites in only 10 microseconds, or 20 times faster than deuterium alone. At 75 million degrees it takes only 3 microseconds, as against 40 for deuterium, while at 100 million degrees it needs only 1.2 microseconds to catch fire, a time, as we have seen, only 0.1 microsecond longer than it took the wartime A-bomb to fly apart. Since the latter held together for 1.1 microseconds at a temperature of about 50 million degrees, it is reasonable to assume that the improved and more efficient models generate a temperature at least twice as high, and that

this is done by holding them together for about 1.2 microseconds.

It can thus be deduced that the only feasible H-bomb is one in which a relatively small amount of a deuterium-tritium mixture will serve as additional superkindling, to boost the kindling supplied by the improved model A-bomb, for lighting a fire with a vast quantity of deuterium. This, it appears, is the real secret of the H-bomb, which is really no secret at all, since all the deductions here presented are arrived at on the basis of data widely known to scientists everywhere, including Russia. And since it is no secret from the Russians, whom the arch-traitor Fuchs has supplied with the details still classified top secret, the American people are certainly entitled to the known facts, so vitally necessary for an intelligent understanding of one of the most important problems facing them today.

A deuterium bomb with a D-T booster would become a certainty if the temperature of the A-bomb trigger could be raised to 150 million or, better still, to 200 million degrees. At the former temperature the D-T superkindling ignites in 0.38 microseconds; at the higher temperature the ignition time goes down to as low as 0.28 microseconds. Now, the D-T mixture releases four times as much energy as plutonium, and the faster the time in which energy is released, the higher goes the temperature. Since four times as much energy is

released at a rate four times faster than in the wartime model A-bomb, it is not unreasonable to assume that the temperature generated would be high enough to ignite the green wood in the bomb —its load of deuterium.

How much tritium would be required for the kindling mixture? On this we can only speculate at present. Since the D-T kindling calls for the fusion of one atom of tritium with one atom of deuterium, and the atomic weight of tritium is three as compared with two for deuterium, the weight of the two substances will be in the ratio of 3 for tritium to 2 for deuterium. Thus if the amount to be used for the kindling mixture is to be one kilogram, it will be made up of 600 grams of tritium and 400 grams of deuterium. Since, as we have seen, it would take eighty kilograms of plutonium to produce one kilogram of tritium, we would have to use up only 48 kilograms of plutonium to create the 600 grams, or the equivalent of one and a half to about five A-bombs, according to Dr. Oliphant's estimate.

But would we need as much as 600 grams of tritium? Such an amount, mixed with 400 grams of deuterium, would yield an explosive power equal to 80,000 tons of TNT, an energy equivalent of 100 million kilowatt-hours. A twentieth part of this amount would still be equal in power to 4,000 tons of TNT, equivalent in terms of energy to 5,000,000 kilowatt-hours. Now one twentieth of

600 grams, just 30 grams of tritium, could be made at a cost of no more than 2.4 kilograms of plutonium. Thus we would be paying only one twelfth to one fourth of an A-bomb (in addition to the one used as the trigger) to get the equivalent of ten A-bombs in blasting power and of thirty times the incendiary power, which would totally devastate an area of more than 300 square miles by blast and of more than 1,200 square miles by fire.

Would 30 grams of tritium be enough to serve as the superkindling for exploding, let's say, 1,000 kilograms (one ton) of deuterium? We shall probably not know until we actually try it. It will largely depend on the temperature generated by our more powerful A-bomb models. If it is true, as Senator Johnson informed his television audience, that they have "six times the effectiveness of the bomb that was dropped over Nagasaki" (which, by the way, had more than twice the effectiveness of the Hiroshima model), it is quite possible that their temperature is as high as 150 million, or even 200 million, degrees. In that case, the extra kindling of a 20-30 gram D-T mixture, with its tremendous burst of 5,000,000 kilowatt-hours of energy in 0.28 to 0.38 microseconds (added to the vast quantity already being liberated by the exploding plutonium, or U-235), might well heat the deuterium to the proper ignition temperature and keep it hot long enough for its mass to explode well within 1.2 microseconds. In any case it would

appear logical to expect that a mixture of 150 grams of tritium and 100 grams of deuterium, which would release an energy equal to that of the Hiroshima bomb, should be able to do the job with plenty of time to spare.

We thus have a threefold answer to the question: Can the H-bomb *actually* be made? As we have seen, the deuterium bomb is definitely not possible. The tritium bomb is theoretically possible, but definitely not practicable. But a large deuterium bomb using a reasonably small amount of a deuterium and tritium mixture as extra kindling is both possible and feasible.

We now also stand on solid ground in dealing with the questions of cost and of the time it would take us to get into production. With these questions answered, we can then decide whether the H-bomb, if made, will add enough to our security to make the effort worth while.

We know at this stage that the H-bomb requires three essential ingredients. It needs, first of all, an A-bomb to set if off. We have a sizable stockpile of them. It needs large quantities of deuterium. We have built several deuterium plants during the war, and they should be large enough to supply our needs. Since it is extracted from water, the raw material will cost us nothing. The only item of cost will be the electric power required for the concentration process, and this should not be above $100 per kilogram, and probably less. The third vital

ingredient, tritium, can be made in the giant plutonium plants at Hanford, Washington. Thus it can be seen that all the essential ingredients of the H-bomb, the costliest and those that would take longest to produce, as well as the multimillion-dollar plants required for their production, are already at hand.

This means that as far as the essential materials are concerned, we are ready to go right now. And as for the cost, it would appear to require hardly any new appropriations by Congress, or, at any rate, only appropriations that would be mere chicken feed compared with the five billion we have already invested in our A-bomb program.

The raw material out of which tritium is made is the common, cheap light metal lithium, the lightest, in fact, of all the metals. It has an atomic weight of six, its nucleus consisting of three protons and three neutrons. When an extra neutron invades its nucleus, it becomes unstable and breaks up into two lighter elements, helium (two protons and two neutrons) and tritium (one proton and two neutrons). They are both gases and they are readily separated. And while lithium of atomic weight six constitutes only 7.5 per cent of the element as found in nature (it comes mixed with 92.5 per cent of lithium of atomic weight seven), there is no need to separate it from its heavier twin, since the latter has no affinity for

neutrons and nearly all of them are gobbled up by the lighter element.

The production of tritium, even in small amounts, will nevertheless be a formidable process. As we have seen, it takes eighty times as many neutrons to produce any given amount of tritium as to produce a corresponding amount of plutonium. Since the lithium will have to compete with uranium 238 (parent of plutonium) for the available supply of neutrons, and since the number of atoms of U-238 per given volume is nearly forty times greater than the number of lithium atoms, the rate of tritium production would be very much slower than that of plutonium. On the other hand, even if it took as much as two hundred times as long to produce a given quantity of tritium, the handicap would be considerably overcome because of the relatively small amounts that may be required. If, for example, we should need only 30 to 150 grams of tritium per bomb, it would take our present plutonium plants only six to thirty times longer to produce these quantities than it takes them to produce one kilogram of plutonium. A hypothetical plant such as the one mentioned in the official Smyth Report, designed to produce one kilogram of plutonium per day, would thus yield 30 grams of tritium in six days.

How much tritium would be needed for an adequate stockpile of H-bombs? Since our primary

reasons for building it are to deter aggression, to prevent its use against us or our allies, and as a tactical weapon against large land armies, it would appear that as few as twenty-five, or fifty at the most, would be adequate for the purpose. On the basis of the larger figure (assuming 30 to 150 grams of tritium per bomb), it would mean an initial stockpile of only 1.5 to 7.5 kilograms of tritium, which would entail the sacrifice of about 120 to 600 kilograms of plutonium. Once this initial outlay had been made, however, our plutonium sacrifice would be reduced annually to only one twenty-fourth of the original respective amounts—namely, 5 to 25 kilograms a year—just enough to make up for the decay of the tritium at the rate of fifty per cent every twelve years.

One of the major problems to be solved, in addition to the main problem of designing the assembly, arises from the fact that the deuterium and the tritium booster will have to be in liquid form. Liquid hydrogen boils (that is, reverts to gas) at a temperature of 423 degrees below zero Fahrenheit under a pressure of one atmosphere (fifteen pounds per square inch). To liquefy it, it is necessary to cool it in liquid air (at 313.96 below zero F.) while keeping it at the same time under a pressure of 180 atmospheres. To transport it, it must be placed in a vacuum vessel surrounded by an outer vessel of liquid air. This would point to the need of giant refrigeration and storage plants,

as well as of refrigerator planes for transporting large quantities of liquid deuterium and its tritium spark plug.

Will the H-bomb, if made, add enough to our security to make the effort worth while? We have seen that the required effort may, after all, not be very great. In fact, it may turn out to be a relatively small one, in view of the fact that all the basic ingredients and plants are already at hand and fully paid for. But supposing even that the effort turns out to be much more costly than it now appears? The question we must then ask ourselves is: Can we afford not to make the effort?

It is true, of course, as some have pointed out, that ten or even fewer A-bombs could destroy the heart of any metropolitan city, while only one would be quite enough, as we know, for cities the size of Hiroshima or Nagasaki. But that neglects to take into consideration the fact that one H-bomb concentrates within itself the power of thirty A-bombs to destroy by fire and by burns an area of more than 1,200 square miles at one blow. Nor does it take into consideration the military advantage of delivering the power of a combination of ten and thirty A-bombs in one concentrated package, which would make it a tremendous tactical weapon against a huge land army scattered over many miles, or its possible enormous psychological effect against such an army.

Most important of all, this view grossly mini-

mizes the apocalyptic potentialities of the H-bomb for poisoning large areas with deadly clouds of radioactive particles. It is a monstrous fact that an H-bomb incorporating one ton of deuterium, encased in a shell of cobalt, would liberate 250 pounds of neutrons, which would create 15,000 pounds of highly radioactive cobalt, equivalent in their deadliness to 4,800,000 pounds of radium. Such bombs, according to Professor Harrison Brown, University of Chicago nuclear chemist, could be set on a north-south line in the Pacific approximately a thousand miles west of California. "The radioactive dust would reach California in about a day, and New York in four or five days, killing most life as it traverses the continent."

"Similarly," Professor Brown stated in the *American Scholar*, "the Western powers could explode H-bombs on a north-south line about the longitude of Prague which would destroy all life within a strip 1,500 miles wide, extending from Leningrad to Odessa, and 3,000 miles deep, from Prague to the Ural Mountains. Such an attack would produce a 'scorched earth' of an extent unprecedented in history."

Professor Szilard, one of the principal architects of the A-bomb, has estimated, as already stated, that four hundred one-ton deuterium bombs would release enough radioactivity to extinguish all life on earth. Professor Einstein, as we have seen, has publicly stated that the H-bomb, if suc-

cessful, will bring the annihilation of all life on earth within the range of technical possibilities. The question we must therefore ask ourselves is: Can we allow Russia to be the sole possessor of such a weapon?

There can be no question that Russia is already at work on an H-bomb. Like ourselves, she already has the plutonium plants for producing both A-bombs and tritium. She can produce deuterium in the same quantities as we can. In Professor Peter Kapitza she has the world's greatest authority on liquid hydrogen.

Furthermore, she has great incentives to produce H-bombs. Since she is still behind us in her A-bomb stockpile, she can, in a sense, catch up with us much more quickly by converting her fewer A-bombs into H-bombs that would be the equivalents of ten to thirty A-bombs each, thus increasing the power of her stockpile ten to thirty times. Equally if not more important from Russia's point of view is the stark fact that an H-bomb could be much more easily exploded near a coastal city from a submarine or innocent-looking tramp steamer, since most of our great cities are on the seacoast, whereas Russia practically has no coastal cities.

Even if we openly announced that we would not make any H-bombs, it would not deter Russia from making them as fast as she could, not only because she would not believe us but also because

her sole possession would greatly weight the scales in her favor. If, God forbid, she finds herself one day with a stockpile of H-bombs when we have none, she would be in a position to send us an ultimatum similar to the one we sent to the Japanese after Hiroshima: "Surrender or be destroyed!"

Valuing their liberty more their lives, the American people will never surrender. But while there is time, would anyone advocate that we run the risk of ever facing such a choice?

III

SHALL WE RENOUNCE THE USE OF THE H-BOMB?

A FEW days after President Truman announced that he had directed work "to continue" on "the so-called hydrogen, or super bomb," a group of twelve eminent physicists, including half a dozen of the major architects of the atomic bomb at Los Alamos, who, no doubt, are playing a similar role in the development of the H-bomb, issued a statement urging the United States to make "a solemn declaration that we shall never use the bomb first," and "that the only circumstances which might force us to use it would be if we or our allies were attacked by *this* bomb." They added that "there can be only one justification for our development of the hydrogen bomb, and that is to prevent its use."

Signers of the statement, unprecedented in the annals of science (with the possible exception of a secret memorandum submitted to the government just before the A-bomb was used), included such outstanding physicists as Hans A. Bethe of Cornell; Kenneth T. Bainbridge of Harvard; Samuel K. Allison, University of Chicago; Dean George B. Pegram, Columbia; C. C. Lauritsen, California Institute of Technology; Bruno Rossi

and Victor F. Weisskopf, Massachusetts Institute of Technology; F. W. Loomis and Frederick Seitz, University of Illinois; Merle A. Tuve, Carnegie Institution of Washington; R. B. Brode, University of California; and M. G. White, Princeton—all, with the exception of Dr. Tuve, professors of physics at their respective universities. Those among them who did not directly participate in the development of the A-bomb played major parts in other scientific wartime projects, such as radar and the proximity fuse.

Implicit in their statement was the first confirmation—indeed, the most authoritative we have had so far from scientists with first-hand knowledge of the subject—that a hydrogen bomb of a thousand times the power of the A-bomb could be made. More than that, they informed us that Russia may complete the H-bomb in less than four years, meaning, of course, that we too could achieve the same goal in the same period. We were thus provided by the experts with a time-table on which we must act if we are not to run the risk of Russia's getting the H-bomb ahead of us, and so being in a position to use it, or threaten its use, against the nations of western Europe, as the greatest blackmail weapon in history.

The statement summarizes in essence the principal points of view that have been advanced so far on what policy we should adopt on the H-bomb, and since it was promulgated by men known to

have definite inside knowledge of the subject, it deserves closer scrutiny than it has hitherto received.

"It was stated correctly," they inform us at the outset,

> that a hydrogen bomb, if it can be made, would be capable of developing a power 1,000 times greater than the present atomic bomb. New York, or any of the greatest cities of the world, could be destroyed by a single hydrogen bomb.
>
> We believe that no nation has the right to use such a bomb, no matter how righteous its cause. The bomb is no longer a weapon of war, but a means of extermination of whole populations. Its use would be a betrayal of morality and of Christian civilization itself.
>
> Senator Brien McMahon has pointed out to the American people that the possession of the hydrogen bomb will not give positive security to this country. We shall not have a monopoly of this bomb, but it is certain that the Russians will be able to make one, too. In the case of the fission bomb the Russians required four years to parallel our development. *In the case of the hydrogen bomb they will probably need a shorter time.*
>
> We must remember that we do not possess the bomb but are only developing it, and Russia has received, through indiscretion, *the most valuable hint that our experts believe the development possible.* Perhaps the development of the hydrogen bomb has already been under way in Russia for some time. But if it was not, our decision to develop it must have

started the Russians on the same program. If they had already a going program, they will redouble their efforts.

Statements in the press have given the power of the H-bomb as between two and 1,000 times that of the present fission bomb. Actually, the thermonuclear reaction on which the H-bomb is based is limited in its power only by the amount of hydrogen which can be carried in the bomb. Even if the power were limited to 1,000 times that of a present atomic bomb, the step from an A-bomb to an H-bomb would be as great as that from an ordinary TNT bomb to the atom bomb.

To create such an ever-present danger for all the nations of the world is against the vital interests of both Russia and the United States. Three prominent Senators have called for renewed efforts to eliminate this weapon and other weapons of mass destruction from the arsenals of all nations. Such efforts should be made, and made in all sincerity from both sides.

In the meantime, we urge that the United States, through its elected government, make a solemn declaration that we shall never use this bomb first.

Before discussing in detail the merits of the proposal that the United States renounce the use of the H-bomb, "no matter how righteous its cause," except in retaliation for its use against us or our allies, it behooves us to examine the effect of our decisions to proceed with the development of the H-bomb on Russia's A-bomb progress.

We know that the H-bomb requires an A-bomb for its trigger. We also have strong grounds for

assuming that, in addition to the A-bomb, an H-bomb will require certain quantities of triple-weight hydrogen, or tritium, as extra superkindling to boost the A-bomb. We know, furthermore, that it takes eighty times as many neutrons to make a given quantity of tritium as it does to make a corresponding amount of plutonium, which, of course, means a reduction in A-bombs.

Hence, should Russia decide to embark on an H-bomb program of her own, or to "redouble her efforts," it would lead inevitably to a serious curtailment in her stockpile of A-bombs. While we would have to make the same sacrifice of plutonium, it is obvious that we can afford the sacrifice much better than Russia, since we already have a sizable stockpile of both plutonium and uranium bombs, whereas she has just begun building her stockpile. The situation for her would be much worse if she has put all her atomic eggs in the plutonium basket without bothering to build the much more complicated and costly uranium separation plants, as the incomplete evidence available would seem to indicate. In that case she would be faced with a serious dilemma indeed, for you cannot have H-bombs without A-bombs, and you cannot have A-bombs without plutonium, and if, as the evidence indicates, she has built her A-bomb program exclusively around plutonium, she would have to sacrifice quantities she could ill afford to spare, at this stage of her development, of the only

element she desperately needs for building up her A-bomb stockpile.

How do we know that Russia's A-bomb is made of plutonium? We have the testimony of Senator Johnson of Colorado, who assured us in his famous television broadcast of November 1, 1949 that "there's no question at all that the Russians have a bomb more or less similar to the bomb that we dropped at Nagasaki, a plutonium bomb." In this single sentence the Senator from Colorado, who as a member of the Joint Congressional Committee on Atomic Energy has access to such information, inadvertently let at least three cats out of the bag. He confirmed that the Nagasaki bomb was made of plutonium (though, in fairness, it must be said that this had been known unofficially for some time); he told us that we had found out not only that "an atomic explosion had occurred in the U.S.S.R.," as the President had announced in carefully chosen words, but that the explosion was that of an atomic bomb and that, more important still, the bomb was made of plutonium. And in doing so he, furthermore, gave away the secret of how we had obtained that information, something the Russians very much wanted to know. Not being a scientist, Senator Johnson obviously did not realize that the split fragments (fission products) of a plutonium bomb differ from those given off by the explosion of a uranium bomb, so that in revealing that we knew what the bomb was made of he

would also be revealing at the same time that we found it out by examining radioactive air samples and finding them to contain fission fragments of plutonium, as well as whole plutonium atoms that escaped fission.

There is thus no doubt that the Russians have built nuclear reactors for producing plutonium from nonfissionable uranium 238. We cannot, of course, be sure that they have not at the same time also built plants for concentrating uranium 235, but the odds favor the negative. We built uranium separation plants at Oak Ridge, Tennessee, and plutonium plants at Hanford, Washington, during the war because we didn't know at the time which method would work, and we gambled on the chance that, by building plants for producing fissionable materials by four different methods, at least one of them might work. Had we known at the time that the plutonium plants were practical, it is quite likely that we would not have invested a billion dollars in building the uranium separation plants. Since the Russians have obviously decided on plutonium plants as the simplest and cheapest (three plutonium plants cost us a total of $400,000,000, whereas a single large uranium separation plant cost half a billion), it is hardly likely that they would consider it worth while to invest in the much more costly uranium separation plants.

As Senator Johnson said in the same broadcast: "We tried out four different methods of making a

bomb and all of them succeeded, but one of these methods was superior to all the others in simplicity and effectiveness, and we told the Russians and we told the world that fact. Of course, they didn't have to make the experiments that we had to make to find out by elimination which method was the most effective and which the one that they should follow."

The evidence is thus strongly in favor of the assumption that Russia has only plutonium plants as her sole source of A-bomb material, whereas we have both plutonium plants and gigantic uranium plants in full operation. If that is so, then our forcing Russia to embark on an H-bomb program, at a time when her A-bomb program is barely started, will place her under a double handicap in her race to catch up with us in A-bombs, and at least to keep abreast of us, if not ahead, in H-bombs. For in this grim race we have a dual if not a triple advantage: our much superior stockpile, both in numbers and no doubt in quality, and our gigantic plants for concentrating U-235, the production of which would not have to be curtailed at all, since tritium can be made only in plutonium plants. In fact, we are now in the process of construction of two great additions to the uranium plant at Oak Ridge.

One may visualize the masters of the Kremlin gnashing their teeth in impotent rage at what they no doubt regard as a diabolical plot on our part

to sabotage their A-bomb effort. Indeed, there can be no question that our decision to proceed with the H-bomb was an answer to Russia's challenge to our atomic supremacy, and it appears quite plausible that one of the motives behind the decision was the knowledge that it would force Russia either to build great additions to her atomic plants, at great expense in money and materials and at the loss of considerable precious time, or to curtail her production of A-bomb material. And while any such motive could not possibly have been the determining factor, the ultimate effect of our decision was the same as though we had succeeded in getting a team of expert saboteurs behind the Iron Curtain to plant a good-sized monkey wrench in the Soviet atomic machinery.

With this in mind we begin to appreciate how dangerous a move it would be, to ourselves and to world peace, if we were to make a solemn declaration at the outset, even before we have a single H-bomb, that we will never use it, "no matter how righteous our cause," unless it is used first against us or our allies. By making such a unilateral declaration, without even making it conditional upon Russia issuing a similar solemn renunciation, we would, in effect, be saying to Russia: "We humbly beg your pardon. We did not realize that we would be putting a nasty monkey wrench in the machinery of your vital A-bomb program. We shall remove the wrench at once so that you may

proceed with your program unhindered by us in any way."

The masters of the Kremlin would, indeed, have every right to laugh long and loud, and to take such foolhardy action on our part as further evidence of what they call "the decadence of the bourgeois democracies." For, once we make such a magnanimous unilateral solemn renunciation of the one weapon that promises to become the greatest single deterrent against war, without even bothering to ask Russia publicly to do likewise, Russia could then proceed calmly at her leisure to build up her A-bomb stockpile, with the complete assurance from us that she need not worry about our H-bomb as long as she does not use one against us or our allies. After she has accumulated an adequate A-bomb stockpile—and fifty to one hundred would be adequate from her standpoint—she would then be in a position, already attained by us now, to proceed with her H-bomb program, knowing full well that we would never use H-bombs against her while she is still without them. And while she obviously could not use anything she does not have, she could well afford to make aggressive war even before she has an H-bomb, or to bide her time until she does, the choice being entirely hers. And if she waits until she has the H-bomb, the decision whether to use it or not would still be entirely hers, so that she

could use it whenever she decides it is to her advantage to do so, whereas we should have to wait on her pleasure, having morally bound ourselves, without qualification, not to use it first, even if our very existence depended on it.

It can thus be easily seen that this "after you, my dear Alphonse" gesture on our part in a matter that may involve our very existence would be more than quixotic. It is likely to prove suicidal. It will not improve the prospects of world peace; on the contrary it will weaken them. It will not enhance our moral stature, since the world does not have much respect for starry-eyed dreamers with their heads in the clouds.

But while we must keep our feet planted on the ground, we need not lose sight of the stars. Our refusal to expose ourselves by giving Russia the great advantages mentioned, does not mean that we retain the right to use the H-bomb indiscriminately as though it were just another weapon. There are, I shall presently show, both legitimate and illegitimate uses to which the H-bomb can be put, and it is the failure so far, even by eminent scientists, to distinguish between these two types of possible uses that is responsible for a great deal, if not all, of the confusion and much futile debate that have followed the President's announcement of his directive to continue work on the hydrogen bomb, and for the flood of verbiage that will con-

tinue to plague and bewilder us until we take time to acquaint ourselves with the facts about the H-bomb.

One of the major difficulties in our approach to the subject stems from the general tendency to talk about the H-bomb as though it were just one weapon, which obviously it is not. As we know, it is several weapons in one package, which can be designed for various uses, depending on the intent of its designer. It is, on the one hand, a weapon that can cause total destruction by blast over a radius of ten miles, or an area of more than 300 square miles, with graduated lesser damage over a much larger area. Secondly, it is a weapon that can produce fires and severe flash burns over a radius of twenty miles—that is, over an area of more than 1,200 square miles. These two functions, destruction by blast and by fire, go together. They are inseparable as far as the bomb itself is concerned, though their relative effects can be regulated by the height from which the bomb is dropped, by the terrain over which it is used, and by its mode of delivery other than by air.

Then, of course, there is the third weapon of terror, the tremendous quantities of deadly radioactive particles that the H-bomb may release in the atmosphere, which, as Dr. Einstein said, would bring within the range of technical possibilities "the annihilation of life on earth." This, however, would depend on the choice and purpose of the

designer. If he so chooses, he can design an H-bomb that would produce only slightly greater radioactivity than its A-bomb trigger. Or he can rig it in such a manner that one bomb would release into the atmosphere the equivalent of nearly five million pounds of radium that would poison the atmosphere for thousands of miles, killing all life wherever it goes. The catchword here is "rig," and the rigging depends entirely, not on the contents of the bomb itself, but on the material of which its outer shell is composed. If, for example, the casing chosen is a material such as steel, the radioactivity produced would be practically harmless. If the shell is made of cobalt, the radiations released would cause untold havoc. The reason for the vast difference is not difficult to understand. The H-bomb, when it explodes, releases tremendous quantities of neutrons, the most penetrating particles in nature. As soon as it is liberated, a neutron enters the nucleus of the nearest element at hand. This may produce a wide variety of changes in the nature of the element penetrated by the neutron, the changes depending on the element. Some elements, such as cobalt, become intensely radioactive, others only mildly so, and still others not at all. Furthermore, each element thus made radioactive has its own characteristic decay period, lasting from seconds to many years, so that the designer of the bomb has a great variety to choose from.

From this it can be seen that, instead of one, there are actually two types of H-bombs—the non-rigged and the rigged. With this vital distinction in mind the problem of its use becomes much more simplified. We are in a position to reach full agreement with the scientists that no nation has the right to use such a "rigged" bomb, no matter how righteous its cause. For the rigged H-bomb would add nothing to the military value of the non-rigged H-bomb, which is already more than enough to achieve any military objective. It would merely be piling horror upon horror for no purpose beyond wanton destruction for its own sake. Its use even in small numbers would ruin large segments of the earth for years. It would, as the scientists said, "be a betrayal of morality and of Christian civilization itself." There can therefore be no question that when this distinction between the non-rigged and the rigged H-bomb is made clear to the American people—something the scientists failed to do—they would overwhelmingly lend their support to a move on the part of our government solemnly declaring that we would never use the rigged H-bomb first; that our only aim in building it is to prevent its use, and that the only circumstances under which we would find ourselves forced to use it would be in retaliation for its use against us or our allies.

We can, and should, make such a solemn declaration unilaterally, regardless of whether Russia

makes a similar declaration. We would lose nothing by doing so from a military or strategic point of view, and we would gain enormously in moral stature and on the battlefront of ideas if we were to do it now. Otherwise we run the risk that Russia might do it first. If she takes advantage of this lost opportunity of ours, we shall have handed her a great moral victory. In fact, the law of nations compels us to make such a declaration. Unlike the A-bomb, in which the radioactivity is part and parcel of the bomb itself, the rigged H-bomb is purposely designed to produce radioactive poisoning in the atmosphere. Since it has to be specially incorporated into the casing of the bomb, it comes under the international convention outlawing the use of poison gas. For there can be no question that a radioactive cloud that may lay waste to whole areas is the most diabolical and deadly poison gas so far invented.

But the twelve scientists do not seem to be satisfied with the mere renunciation of the rigged H-bomb. They ask us to declare that we would not be the first to use even the non-rigged bomb, on the grounds that it "is no longer a weapon of war, but a means of extermination of whole populations." This requires closer scrutiny.

It has become customary to think of the A-bomb, and now of the H-bomb, as purely strategic weapons for destroying industrial centers producing war materials, thus depriving the ar-

mies at the front of the vital sinews of war. It is also regarded as a weapon of superterror to bring a nation to its knees, as the A-bomb did in Japan. Since industrial centers, particularly in the United States, are densely populated areas, and since, conversely, all large cities are also important industrial centers, it has become almost axiomatic that the A-bomb and the H-bomb could be used only in strategic bombing of large centers of population, which, of course, means the wholesale slaughter of millions of civilians and the wiping out of cities with populations of more than 200,000.

But to think along such lines would be thinking of World War III, which we must do our utmost to prevent, in terms of World War II, which would be just as fatal as thinking in terms of World War I was to the French in World War II. For even a cursory examination of the situation should reveal that strategic bombing of cities may, and very likely would be, as obsolete in the next war as trench warfare was in the last. One does not have to be a military expert to know the reason why. In the last war strategic bombing was resorted to in order to deprive the army at the front of weapons and supplies. Obviously, if you had a superweapon that could wipe out an entire army in the field or on the march at one blow, there would be no further need of depriving an army that was no longer in being.

That is exactly what the non-rigged H-bomb is.

As a blast weapon, we have seen, it can cause total destruction of everything within an area of more than 300 square miles. As an incinerator it would severely burn everything within an area of more than 1,200 square miles. It is thus the tactical weapon par excellence. No army in the field or on the march could stand up against it. Had we possessed it at the Battle of the Bulge, just one could have wiped out the entire Bulge. If the Nazis had had it before D-Day, one would have been enough to wipe out our entire invasion army even before it landed; or they could have waited and wiped out our entire Normandy beachhead. In a word, the non-rigged H-bomb has produced a major revolution in tactics and strategy. It has made strategic bombing of cities as obsolete as the trench of World War I, except as a weapon of pure terror and wanton wholesale destruction of life and property. It would be absolutely useless to the victor as well as to the vanquished, as the victor would have no spoils of victory left and would have to rebuild what he had needlessly destroyed.

Viewed in this light, the non-rigged H-bomb, just because it is the weapon for the annihilation of armies, becomes vis-à-vis Russia, the greatest deterrent against war that could possibly be devised in the present state of affairs. For, after all, the only great advantage Russia has over us today is her land army and her great reserve of manpower. The non-rigged H-bomb, supported by a

large and up-to-date air force capable of delivering it either by air or from a seized airhead behind the lines, could nullify that advantage in a few hours. At least the threat of such a possibility will always be there. It is therefore doubtful, to say the least, that any group of men would willingly take such a risk.

Since the greatest and most effective use of the non-rigged H-bomb would thus be as a tactical weapon against armies in the field, while its strategic use against civilian populations would be simple wanton destruction from the point of view of both victor and vanquished, then not only morality and Christian civilization but plain common sense would dictate the wisdom of our solemnly declaring right now that we will never be the first to use either the non-rigged H-bomb or even the A-bomb against civilian populations, and that the only circumstance that would compel us to use them so would be in retaliation for their use against us or our allies. In fact, we could renounce strategic bombing altogether. By doing so we would gain one of the greatest moral victories, for then if Russia failed to make a similar declaration, as she most likely would, she would stand before the world as a nation bent on wholesale slaughter of civilian populations. We have nothing to lose and everything to gain by such a declaration, and the sooner we make it the better.

Should we make such a declaration, it would

place Russia in an embarrassing position indeed. For while as a tactical weapon the non-rigged H-bomb offers us great advantages as a counterforce to neutralize her huge army, she can use the H-bomb, both the rigged and the non-rigged, as a constant threat against our densely populated cities. As Senator Brien McHahon, of Connecticut, chairman of the Joint Congressional Committee on Atomic Energy, has warned, an H-bomb attack "might incinerate 50,000,000 Americans—not in the space of an evening but in the space of a few minutes." We have eleven cities of one million or more inhabitants, whereas Russia has only three or four. We have forty cities of 200,000 and over, inhabited by 40,000,000, or 27 per cent of our population, whereas Russia has only twenty cities of 200,000 and over, inhabited by only 20,000,000, or 10 per cent of her population. Furthermore, her industries are now largely dispersed, whereas our industries are highly centralized. Russia would thus get much the worse of the bargain if she were to accept our challenge to renounce the use of strategic bombing, particularly that of the A- and H-bombs, while we still retain the right to use them in tactical bombing against her armies.

Suppose Russia in this dilemma, and recognizing the need to avoid the moral opprobrium of the peoples of the world that her refusal to meet our renunciation would entail, comes forth with a counterproposal to renounce the use of both

A- and H-bombs altogether, as strategic as well as tactical weapons, thus exchanging the elimination of the threat of the annihilation of our teeming cities and industries, for the removal of the threat of destruction to her armies. Suppose that at the same time she repeats her demand, frequently voiced by her in the United Nations, that all stockpiles of A- and H-bombs be destroyed and a convention signed to outlaw their uses. The world already knows the answer, for we have already made it again and again.

Immediately after the close of the last war we declared our readiness to give up the A-bomb. In 1946, at a time when we were the sole possessor of the bomb, when we had every reason to believe that our monopoly would last for a number of years, we submitted a far-reaching plan for the international control of atomic energy, the most generous offer by far ever made by any nation in history. In this historic plan we not only declared our readiness to give up our stockpile of A-bombs and to agree to refrain from further production; we even offered to give up our sovereignty over our multibillion-dollar atomic plants to an international agency. We further agreed to submit to unhindered, free inspection by such an agency to assure the world, and Russia in particular, that we were not manufacturing A-bombs, or A-bomb materials, in secret. No nation in history had ever gone so far in its desire to show its goodwill and its peaceful

intentions as to make a voluntary offer to surrender the world's most powerful weapon of war, and an important part of its sovereignty to boot. The offer still stands. It has been enthusiastically endorsed by all the members of the United Nations except Russia and her satellites. After three years of futile negotiations and discussions Russia still insists that she would not surrender any part of her sovereignty or submit to the only kind of inspection that could assure the world against clandestine production of atomic bombs and materials.

Hence, should Russia demand that we renounce the right to use the A- and H-bombs not only as strategic but also as tactical weapons against her armies in exchange for a similar offer on her part, it would on the face of it be a mere repetition of her earlier efforts to trick us into giving up our greatest weapons while she remained free to produce them in secret, since she insists upon her right to retain ownership of the atomic plants and materials and upon the inspection of only those plants she acknowledges to exist, thus making it impossible to find plants whose existence she does not admit. To accept such an offer would be tantamount to surrender, since our giving up the right to use the H-bomb as a tactical weapon against her armies would leave her free to march into the countries of western Europe. It would then be too late to stop her, for we could not drop the H-bomb on the cities of western Europe. The only time to

stop Russia's armies is before they cross into the territory of our allies, during the crucial period when they are mobilized in large numbers and on the march.

The American people, and the other free peoples of the world, could not agree to such a scheme to disarm them in advance and thus give the masters of the Kremlin a free hand. To do so would not prevent war, it would encourage it. It would not even delay it, it would hasten it. Instead of being preventable, it would become inevitable. We wouldn't even save our cities from the fate of strategic bombing with A- and H-bombs, since the Kremlin has never kept its promises when they did not suit its purposes. When we had lost our greatest chance to wipe out her armies in one mighty blow, Russia would be in a position to trade our industries and cities for her dispersed and still primitive industrial plants and cities. If at that stage she should offer us, as well as our neighbors to the south and Britain and her Dominions, independence and complete sovereignty, while she assumed hegemony over all of Europe and Asia, could we then refuse, at the risk of the lives of our millions? Supposing the nations of western Europe, overrun by the Red Army, become "people's democracies," Russian style, would we risk our millions to liberate nations whose governments would by then have joined the ranks of our enemy?

These are the brutal facts that would confront

us were we to renounce the right to use A- and H-bombs as tactical weapons against armies in the field. As long as we retain that right, the chances are good that we could prevent global war, for no nation would be likely to risk such a war in the face of the possibility that the main bulk of its armies might be wiped out at the outset. If we give up that right, we would also prevent war—by surrendering in advance. Russia, of course, might figure that she could still make war, when she decides the time is ripe, taking the calculated risk that we would not use the A- and H-bombs against her armies for fear of her retaliation against our cities and industries. But whether she would consider that calculated risk worth taking would depend on how good our defenses were. Senator McMahon's warning that an H-bomb attack "might incinerate 50,000,000 Americans . . . in the space of a few minutes" would become a possibility only if we allowed ourselves to be surprised for a second time by a "super Pearl Harbor," which, of course, is inconceivable. While it is generally agreed that it is impossible to decentralize our cities and industries, because of the tremendous cost (estimated at $300 billion) and the short time at our disposal between now and the ultimate showdown, when Russia is expected to be ready to make major moves at the risk of "accepting" war, we have many advantages not possessed by Britain and Germany during the last war as far as defenses

against strategic bombing were concerned. Britain, as well as Poland, Holland, and Belgium—little, densely populated countries—were within very short range of Germany's airfields. So was Germany, in her turn, within easy range from Britain. Radar, as compared with its modern types, was primitive in quality and inadequate in quantity. Automatic antiaircraft guns, interceptor planes, and night fighters were either nonexistent in the early days of the blitz or in a crude stage of development compared with present equivalents.

How vastly different is our situation today vis-à-vis Russia! Instead of a short hop across the English Channel she would have to cross the Atlantic or the Pacific to reach our continent, whereas we can reach her heartland from bases all around her borders. It is unthinkable that any of her bombers can cross either ocean without being detected hundreds of miles before they reach our shores. With modern radar devices, which are constantly being improved, and fleets of fast interceptors far in advance of anything Russia could develop, we would destroy them long before they would do us any harm. If she attempts to fly over the North Pole, she will still have to cross all of Canada before she can reach us, and if we and our Canadian friends are on the alert, as we must and shall be, any hostile planes could be detected and destroyed over the Arctic.

There is, of course, the possibility of exploding

an H-bomb some distance off shore from a submarine or from a tramp steamer, but here, too, eternal vigilance will be the price of our liberties and our lives. There can be no question that we shall succeed in finding the answer to the detection of the Snorkel-type submarine and master it just as we mastered the earlier types. American ingenuity and superior technology have never failed yet in the face of an emergency, and it is unthinkable that they should fail now.

We often hear it said that an enemy could smuggle an A-bomb in small parts into this country and assemble it here. While such an operation is possible, its successful execution against a nation fully on guard is highly improbable. As for the H-bomb, it requires large quantities of liquefied gas, which must be kept in a vacuum surrounded by large vessels of liquid air. In addition it must have its A-bomb trigger and other complicated devices. All this makes its surreptitious smuggling into a country such as ours even more improbable.

We have had it dinned into our ears for so long that there is no defense against the atomic bomb, and that the only choice confronting us is "one world or none," without anyone taking the trouble to challenge these two pernicious catch-phrases, that we have accepted them as gospel truth, particularly since they were uttered by some of our more articulate atomic scientists. That scientists should at last step out from their laboratories and

classrooms to take an active interest in public affairs is highly commendable and welcome. But that does not give them the right to take advantage of the great respect and confidence the public has for them with utterances that serve only to create fear and hysteria and a sense of helplessness, while at the same time offering remedies they know to be unattainable.

The truth of the matter is that there can be and there is a defense against atomic weapons, as against any other weapon. Basically it is the same as the defense against submarines or enemy bombers: detect them and destroy them before they reach you. The difference is largely a matter of degree. Since the atomic-bomb carrier can do greater damage, the measures of defense against it must be correspondingly greater. With the aid of the vast stretches of the Atlantic and the Pacific, augmented by an effective radar and interceptor system, on the one hand; and with effective counter-submarine measures on the other, the odds would be against a single A- or H-bomb reaching our shores.

Faced with such an impregnable system of defense, and with a threat of the swift annihilation of its armies as soon as they begin marching for war, the Kremlin could no longer, unless its masters went completely berserk, regard war, or even a challenge to war, a risk worth taking. The cold war may get warmer, as it did in Korea, but as

long as we keep our heads and don't give way to fear and hysteria, trusting in God and keeping our H-bombs "wet," it may never reach the boiling-point.

And we have in addition a weapon even more powerful than the H-bomb or any other physical weapon, which instead of bringing misery and death would bring new life and new hope to hundreds of millions now enslaved. We have not yet even begun to fight on the battlefield of ideas, in which we can match freedom against tyranny, friendship against class hatred, truth against lies, a society based on the respect and dignity of the individual and the giving of full scope to human aspirations against a society modeled after the beehive and the ant-heap.

"Real peace," former Assistant Secretary of State Adolf A. Berle, Jr., said in the *New Leader*, "is deeper than absence of war. That will be won in the realm of philosophy and ideas. Indeed, the great reason for preventing war is to permit ideas to meet ideas on their own merits. . . . The statesman's business is to keep the conflagration at bay and give ideas their chance, relying on the moral strength of the ideals he represents to bring to their support the masses throughout the world." In such a war of ideas, he adds, there could be no doubt about the outcome, as the West can oppose all its positives against Moscow's negatives. We meet "a betrayed revolution, in a decadent im-

perialist, dictatorial phase, building an empire on the negatives of human behavior. Such empires engage no permanent loyalties; they invariably break up. War would defeat this empire in any case. First rate statesmanship can avoid that war."

In the words of General George C. Marshall, "the most important thing for the world today is a spiritual regeneration. . . . We must present democracy as a force holding within itself the seeds of unlimited progress for the human race. We should make it clear that it is a means to a better way of life within nations and to a better understanding among nations. Tyranny inevitably must fall back before the tremendous moral strength of the gospel of freedom and self-respect for the individual."

As an advance army in this war of ideas we already have a fifth column of millions waiting for our signal to march, the millions of the enslaved satellite countries—Poland, Czechoslovakia, the Baltic countries, Hungary, Bulgaria, Rumania—as well as millions upon millions behind the Iron Curtain in Russia itself. The greatest mistake made by Hitler was his failure to utilize the readiness and eagerness of a large percentage of the Russian masses to turn against their oppressors. When the Nazi armies marched into the Ukraine, large numbers of Ukrainians, who had been longing for independence for centuries, greeted them as their

liberators with the traditional bread and salt, symbol of welcome. Russian soldiers surrendered by the thousands and they, along with the men of the villages, volunteered in great numbers to fight against their enslavers. In the hearts of millions of Russians behind the front, the longing for liberty, never extinguished, was given its greatest stimulus since the days when they overthrew the Czarist regime. They, too, were waiting for the Germans to give them back the revolution the Communists had stolen from them with lies and deceit.

With the stupidity characteristic of all criminals, Hitler and Himmler proclaimed that the Russians were to be treated as an "inferior race." Everywhere their armies went they burned and pillaged and raped. Instead of liberators they turned out to be most savage barbarians, who behaved even worse than the commissars. It was this inconceivable folly of Hitler, as well as our Lend-Lease, that played a major role in enabling the Kremlin to win the war.

The Russian masses and those of the enslaved satellite countries are still waiting for their liberators. The masters of the Kremlin know it, but they hope that, like the Nazis, we will be too stupid to take advantage of it. If a war ever breaks out, we shall have millions joining our ranks provided we do not destroy these millions, those not in uniform, with A- or H-bombs in the strategic

bombing of their cities. But we should not wait until a war breaks out. We must begin mobilizing them right now for the war of ideas.

The so-called Iron Curtain is a fake, like the rest of the Communist set-up. It is made of tinsel and is full of thousands of holes, through which we can pass if we will. Those thousands of miles of border ringing the vast Russian Empire could be utilized as great thoroughfares of ideas, to be smuggled to the millions waiting for them. There isn't a guard on those borders who couldn't, with the proper approach and inducements, be enlisted in our army of ideas. In addition to flooding the air over Russia with tiny balloons, each carrying a message of freedom and hope, we could also smuggle into the country small radio receiving sets by the millions to bring the Voice of America to millions of Russian homes. We could attach to those balloons small loaves of bread, packages of cigarettes, little trinkets for babies, nylon stockings for women, on a scale that no police could cope with. Nor could the Kremlin risk forbidding it, as that would place it in the position of further depriving its starved and hungry people of things they badly need and want.

With these weapons on the battlefront in the war of ideas, and with the A- and H-bomb to give the Kremlin pause, we would be well on the way to win any war, cold or hot. Our justification for building the hydrogen bomb is thus not merely to

prevent its use, but to prevent World War III, and to win it if it comes. We are not building it to bring Russia to her knees. We are building it to bring her to her senses. We must make the Kremlin realize with General Marshall that "tyranny inevitably must fall back before the tremendous moral strength of the gospel of freedom and self-respect for the individual."

IV

KOREA CLEARED THE AIR

As this is being written, the Korean war is just one month old. By the time these lines appear in print we may know whether the naked Communist aggression on the Republic of South Korea was an episode, a prelude, or the first act of World War III. But whatever history records, the first flash of the Communist guns, supplied by the Kremlin, has revealed to the free world at last the face of the enemy in all its hideousness. It brought the first phase of the so-called cold war to a definite end. It aroused freedom-loving peoples everywhere and put them on the alert. It served as a powerful headlight in the night, revealing many dangerous curves on the road ahead. It has given the United Nations its first great opportunity to display its vitality for all the world to see.

Among other things, the flash of the North Korean guns has illumined for us more clearly than ever before the path we must follow in our policy on atomic weapons, both the A-bomb and the H-bomb. It has revealed the extreme danger lurking in any plan to outlaw production and use of atomic weapons in a world constantly threatened by a savage dictatorship, ready to pounce on it at the first sign of weakening in its armor.

The flash of the Red guns, in the first place, made it clear to free men everywhere that to renounce our right to the production of atomic weapons as potentially the greatest deterrents against the further spread of Communist aggression, and as the most powerful defenders of the spiritual and moral values without which our way of life would become meaningless, would allow the Red Army to overrun what remains of the free world. Such a move on our part, for the present and the foreseeable future, may herald the last appearance of free men on the stage of history. It would be, as the Goncourt brothers feared, "closing time, gentlemen!"

In addition to warning us what we must not do, the Red guns also gave warning of a more positive nature. They warned us to make all haste in the construction of the hydrogen bomb, to get it ready as soon as possible, against the eventuality that Russia may decide it would be to her advantage to precipitate World War III before our H-bomb is ready. Instead of the estimated pre-Korea timetable of three years, it now becomes a vital necessity for us to complete our H-bomb, and facilities for its production at a speedy rate, within a year. And if the history of our development of the A-bomb may serve as an example, it almost becomes a certainty that we shall do so. While we may not announce it to the world, we have good reason to expect that the first H-bomb will be

ready for testing sometime in 1951, possibly in early summer.

This forecast is not based on merely guesswork. When we decided to go all out in developing the A-bomb—and we didn't really go to work in earnest until May 1943—nobody knew that it could be successfully made. There were two enormous major problems to be solved, and solved in time to be of use in winning the war. One was to produce unheard-of quantities of fissionable materials (U-235 and plutonium), literally in quantities billions of times greater than had ever been produced before. Nobody knew whether it could be done or how it could be done. Three gigantic plants were built, at a cost of $1,500,000,000, on the mere chance, "calculated risk" we called it, that one of them would work. As it turned out, they all worked, some more efficiently than others, though all contributed to the shortening of the war. The second major problem, among a host of smaller ones, all important to the successful attainment of the goal, was how to assemble the materials produced in the billion-dollar plants into a bomb that would live up to expectations. Both major problems had to be solved simultaneously. The designing of the bomb went on for more than two years with only trickles of the active material.

Yet despite all these enormous difficulties the A-bomb was completed for testing in about two years and three months after the beginning of the

large-scale effort. Compared with the enormousness of the problems that had to be solved, and were solved successfully in this remarkably short time, the problems still to be solved for building the hydrogen bomb appear relatively simple, since all the materials required and the plants to produce them are already built, paid for, and operating successfully. As already pointed out, we have the A-bombs to serve as triggers, large stockpiles of deuterium, and the refrigeration equipment and techniques to liquefy it. We have an adequate supply of lithium for the production of tritium, which, as explained earlier, would be used as the extra kindling to the A-bomb match. And we have, of course, our gigantic plutonium factories at Hanford, Washington, in which the lithium could be converted into tritium in the desired amounts.

Thus, instead of having to start from scratch as we were forced to do with the A-bomb, we have at hand all the necessary ingredients for the H-bomb with the possible exception of sufficient tritium, and since we have the plutonium plants, greatly expanded and improved since the end of the war, it is reasonable to make a "guestimate," to use a word popular in wartime, that a few months should suffice for them, if they are employed exclusively for that purpose, to produce tritium in proper amounts.

That we have decided to complete the construction of the H-bomb in the shortest possible

time was made clear on July 7, two weeks following the Communist attack on South Korea, when President Truman asked Congress to furnish $260,000,000 in cash "to build additional and more efficient plants and related facilities" for materials that can be used either for weapons or for fuels potentially useful for power purposes. The appropriation, he said, was required "in furtherance of my directive of January 31, 1950," in which he had ordered the Atomic Energy Commission "to continue its work on the so-called hydrogen bomb"; and this was further clarified in a letter to the President by the Budget Director, Frederick J. Lawton, recommending the money request, to the effect that the materials to be produced in the proposed plants could be used for either atomic bombs or hydrogen bombs. Since the only type of plant that could produce materials for both the A-bomb and the H-bomb is a nuclear reactor for producing plutonium, and since tritium is the only H-bomb element that could be produced in a plutonium plant, the request by the President may be interpreted as the first, though indirect, official confirmation that tritium is looked upon as one of the ingredients necessary for a successful H-bomb. We were given a hint of a possible time-table when it was revealed that the all-cash request would have to be obligated in one year though its actual disbursal could be spread over four years. This suggests the possibility that the nuclear re-

actors for the large-scale production of tritium might be rushed to completion within one year.

While these new reactors for the production of tritium are being built, we can convert all our Hanford reactors for that purpose so that no time need be lost. Whatever amounts of plutonium would have to be sacrificed by diverting the Hanford plants from plutonium to tritium would be offset by the new uranium concentration plants at Oak Ridge, and by the fact that we already have a large stockpile of both U-235 and plutonium accumulated over a period of five years.

The one and only major problem to be solved is how to assemble into an efficient H-bomb the materials we already have at hand or will have in a few months. Here, too, we are much farther advanced than we were at the time we decided to build the A-bomb, as we are not called upon to start from scratch. For whereas in the early days of the A-bomb development scientists were doubtful whether it could be made at all and were actually hoping that their investigations would prove that it was impossible, for the Nazis as well as for us, no such doubts seem to exist in the minds of those most intimately associated with the problem. On this score we have had more than hints from a number of those in the know, among them Senator McMahon. "The scientists," he said in a historic address to the United States Senate on February 2, 1950, "feel more confident that this most hor-

rible of armaments [the hydrogen bomb] can be developed successfully than they felt in 1940 when the original bomb was under consideration. The hydrogen development will be cheaper than its uranium forerunner. Theoretically, it is without limit in destructive capacity. A weapon made of such material would destroy any military or other target, including the largest city on earth."

What is this confidence based on? Scientists are a very conservative lot, not given to jumping to conclusions without experimental evidence on which to base them. I remember well the agonizing hours preceding the test of the first A-bomb in New Mexico, when everyone present, particularly the intellectual hierarchy that was most responsible, was beset by grave doubts whether the A-bomb would go off at all, and if it did, whether it would live up to expectations or turn out to be no more than an improved blockbuster. Very few, if any, felt confident that it would be as good as it finally turned out to be. For example, in a pool in which everyone bet a dollar to guess the ultimate power of the bomb in terms of TNT, Dr. Oppenheimer placed his bet on 300 tons. This makes it evident that the scientists were not very confident even as late as 1945, up to the very last minute, when "the brain child of many minds came forth in physical shape and performed as it was supposed to do."

If the scientists are more confident today than

they were in 1940, and even, it would seem, in 1945, when the bomb stood on its steel tower ready for its first test, it can only mean that their confidence is based on innumerable experiments carried out during the five years that have elapsed since Hiroshima. By the semiannual reports to Congress by the Atomic Energy Commission, and reports presented before the American Physical Society, or published in official publications, by members of the Los Alamos Scientific Laboratory and other leading institutions, we have been officially informed of many experiments that have been carried out on nuclear reactions between deuterons and deuterons, tritons and tritons, and deuterons and tritons—namely, the very reactions to be expected in an H-bomb using deuterium, tritium, or a mixture of the two. This makes it obvious that during the five years since Hiroshima we have accumulated a vast body of knowledge about the reactions necessary for a successful H-bomb. Furthermore, this gives us the assurance that we are five years ahead of Russia on the H-bomb as well as the A-bomb, since we have had plutonium plants in which to make tritium for at least five years, whereas she has just placed her plutonium plants in operation and, as we have seen, can ill afford to sacrifice the vital plutonium she needs for building up her A-bomb stockpile to begin experiments we had most likely carried out five years ago.

The best evidence so far that we have made much progress during the past five years on the design of the H-bomb—evidence strongly indicating that it had passed the blueprint stage and was ready for construction—was supplied recently by Lewis L. Strauss, a member of the original Atomic Energy Commission, when he revealed that "the greatest issue of division" (between himself and other members of the AEC) "was whether or not to proceed with the hydrogen bomb, as for some time I had strongly urged to do." Now, Strauss, who went into the Navy in World War II as a lieutenant commander and rose to be a rear admiral, is a leading financier of wide experience, so it may be taken for granted that if for some time he had "strongly urged" proceeding with the hydrogen bomb, it must have been because he had been assured by the scientific experts that it was feasible. Men of his background and experience do not "strongly urge" the diversion of resources to projects unless they are strongly convinced that the project is both practical and feasible. His words, when read in the light of statements by other members of the AEC, suggest that the division of opinion on this score among the members of the Commission was not over the feasibility of the H-bomb but over the belief that the A-bomb was good enough as long as we were its sole possessors and that we could maintain our advantage

for a long time by building more and better A-bombs.

On the other hand, the fact that the majority of the AEC did not agree with Strauss on the necessity of proceeding with the hydrogen bomb must certainly not be interpreted to mean that they halted all studies on the subject, for that would be charging them with gross negligence. It is much more reasonable to assume that the "greatest issue of division" (mark the use of the word "greatest," which indicates many a heated debate) was whether or not to proceed at once with the actual building of the bomb, after it had been fully designed and shown to be feasible in a host of painstaking studies over a period of at least four years.

There can therefore be no question that as soon as the President issued his directive to the AEC "to continue" its work on the hydrogen bomb, the first item on the program was to proceed at once with the production of tritium in sizable amounts, since all known facts point to the need of tritium as extra kindling for the A-bomb trigger. We can also be sure that the production of whatever other auxiliary paraphernalia may be necessary was at once placed on the top-priority list. By the end of 1950, if not earlier, we should thus have all the necessary materials ready in the desired amounts. Meantime, we can be sure that our top scientists have been putting the finishing touches on designs for assem-

bling the materials—the *finishing* touches, since there can be no doubt that the blueprints for a successful H-bomb have been completed for at least a year and possibly for three or four. It would be unthinkable that we were so careless as to drop all work on such a vital matter, which as far back as 1945 appeared to be a definite possibility.

For this we have no less an authority than Dr. Oppenheimer. In an article in the book *One World or None,* published late in 1945, discussing atomic weapons of the future, he described bombs "that would reduce the cost of destruction per square mile probably by a factor of 10 or more," which, as we now know, would be a bomb of a thousand times the power that destroyed Hiroshima—namely, a hydrogen bomb. "Preliminary investigations" of proposals for such a bomb, Dr. Oppenheimer wrote at that early date, "appeared sound." If the preliminary investigations "appeared sound" to scientists such as Dr. Oppenheimer in 1945, and bearing in mind President Truman's orders to the AEC in 1950 "to continue its work," we can only conclude that the interim years produced results far beyond the preliminary stage, when they merely "appeared" to be sound. Judging by the reaction of some leading physicists to the President's order, the H-bomb appears to be an ominous reality, a completed architectural plan requiring only a few polishing touches. In a word, we are almost ready to go.

And while Dr. Bethe estimated that it would take three years to complete the first H-bomb, we must remember that he spoke several months before the guns of Korea gave the alarm. And we must not forget that had it not been for the threat of the Nazis we might not have had the A-bomb in less than twenty-five and possibly fifty years, according to the best estimates, though the present Communist threat might have reduced the time considerably.

Furthermore, we also have the word of Senator McMahon, who should know, that "the hydrogen development will be cheaper than its uranium forerunner." This lends weight to the earlier deduction that only relatively small amounts of tritium will be necessary, since, as we have seen, large amounts would be prohibitively costly in terms of vast quantities of plutonium. Small amounts of tritium, in turn, mean that it would take a relatively short time to produce them. A reasonable "guestimate," assuming that 150 to 300 grams of tritium would be required, is that such amounts could be produced within a few months, particularly if we employ all our huge plutonium plants at Hanford on the task of producing tritium.

It is therefore within the realm of possibility that when we carry out the announced tests of the latest models of our A-bombs at Eniwetok, sometime in the spring or summer of 1951, one of them will be the first H-bomb. It may not be the best

model, and it need not be the equal in power to a thousand wartime model A-bombs. In fact, it would be highly inadvisable to use such a bomb in a mere test. It will be an H-bomb, nevertheless, and from it we shall learn how to make bigger and better ones, which is all that a test is supposed to do. For unlike the A-bomb, which cannot be made below or above a certain size, the H-bomb can be made as small or as large as the designer wants it to be. As Professor Bacher has pointed out, the H-bomb is "an open-ended weapon."

One of the major outcomes of the Korean aggression instigated by the Kremlin has thus been to bring the H-bomb into being much sooner than it would otherwise have been. And that is only one branch of the chain reaction that the Korean guns have set in motion.

In addition to unmasking completely the Kremlin's ultimate intentions to enslave mankind, and alerting the free nations of the world to the danger facing them as they had not been alerted since Hitler's attack on Poland, the flash of the Korean guns has also shed new light on the Politburo's strategy of conquest. The best-informed opinion in the summer of 1950 holds that the Kremlin has decided on a series of little wars that would slowly drain our lifeblood and ruin our economy, and thus bring about the collapse and ruin of the rest of the world's free nations, rather than force a global war, German style. Among other reasons for

such a strategy—and there are many logical reasons for it from Russia's point of view—is the fact, already become evident in Korea, that in such little wars, fought with Russian equipment and other people's blood, we would not use atomic weapons of any kind, not only because there are no suitable targets, but because dictates of humanity make the use of such weapons on little peoples, caught in the net of Communism, wholly inconceivable. By deciding on a series of little wars, over a prolonged period, one following the other or coming simultaneously, Russia may thus figure that she could gain her ultimate objective in the cheapest possible way, while at the same time making sure that our atomic-bomb stockpile is wholly neutralized.

If this turns out to be true, we would at least escape atomic warfare, and since we, and the rest of the civilized world, fervently wish to avoid being forced to use atomic weapons, this would be all to the good. But we must also take into consideration the possibility that the very decision on Russia's part to wage little wars and avoid a global war may have been greatly influenced by the fact that we have a large stockpile of A-bombs while her stockpile is still negligible, forcing her to adopt a strategy in which our superiority would be nullified. It is also possible that after her first experience with the production of A-bombs she may have realized that it would be much too costly to try to catch up with us and have therefore decided

on a strategy in which atomic weapons could not possibly play any part. On the other hand, it may also mean that she will not risk a global war until she has built up an adequate stockpile of her own, meantime softening us up with a series of little wars.

With all this in mind, it behooves us to take a closer look at our program for the outlawing of atomic weapons and the placing of atomic energy under international control. It was a noble ideal, one of the noblest conceived by man: the most powerful nation in the world voluntarily offered to give up the right to produce or use the greatest weapon ever designed. Alas, it almost died at birth, and now, after four years of nursing in an incubator, the Korean guns have given it a fatal blow. We might as well face the facts squarely: the majority plan for the international control of atomic energy, the only acceptable plan possible, is dead, one of the first casualties of the Korean guns.

We still talk about trying to find ways for compromise between our plan, accepted by all the nations outside the Iron Curtain, and that of Russia. We are still talking, at least officially, as though somehow a compromise can and will be found. The truth of the matter is that the plan as it stands today is completely out of tune with the times. As we look on it by the light of the North

Korean guns, it becomes clear that it is wholly visionary, without any relation to the realities.

We still talk as though our original offer still stands. The truth of the matter is that even were the impossible to happen and Russia were to say to the world: "We have been mistaken. We accept the American and the majority plan *in toto* without any reservations," we should be forced to say: "Sorry, it is too late, you have missed your chance. Your actions have made the plan unworkable, since it cannot possibly work in an atmosphere of mutual distrust and the constant threat of little wars!"

And even if wise diplomacy prevented us from saying it in such blunt language, and though we may still find it expedient to pay lip service to the majority plan, so that Russia could not use it in her propaganda war as evidence that we were insincere from the very beginning, we would have to wriggle to get out of the very serious predicament in which Russia's acceptance would place us. And even if diplomacy dictated that we sign a convention with Russia to outlaw production and use of all atomic weapons, to destroy our stockpiles and hand over all our atomic plants to an international atomic authority, as our present plan calls for, there can be no question that such a convention could never muster the approval of even a majority of the Senate, and certainly not the required

consent of two thirds of the Senate called for by the Constitution. What is more, such a rejection would have the overwhelming approval of American people, once the facts were made clear to them, and any administration daring to enter such a pact would be overwhelmingly defeated.

All this has been so evident for more than two years that it is remarkable that the Russians have failed so far to take advantage of our potential embarrassment and thus win one of their greatest victories on the propaganda front. In fact, their failure to do so, with the sure knowledge that they would risk nothing by accepting a plan that would most certainly be rejected by our own people, not only reveals lack of subtlety on their part, but appears on the surface as crass stupidity, the same type of stupidity displayed by Hitler, which appears to be an inevitable trait of all monolithic dictatorships that must lead to their ultimate undoing.

The time has come for us to stop talking about giving away our greatest weapons, the only ones, as President Truman and Winston Churchill have told us, that have kept the Red Army hordes from overrunning the free world. It is time for us to face reality and place the blame where it belongs. The evil does not lie in weapons per se. It lies in war itself. It is no evil to build and possess the most powerful weapons at our command with which to defend ourselves against a ruthless aggressor. On

the contrary, it would be an evil thing to throw away the principal weapon standing between us and possible defeat. It is no evil to use a weapon to destroy your enemy just because your weapon happens to be the most powerful in existence. It is no greater evil to destroy thousands of your enemy in one great flash than to destroy them by goring them with bayonets. The real evildoer is the nation that starts an aggressive war. Those attacked have the right and duty to defend themselves by all means at their command.

Our confusion has been the result of our first use of the A-bomb to destroy a city with thousands of its civilian population. Let us admit that the mass bombing of large populated cities (which, by the way, was started by the Nazis) is wholly inexcusable with any kind of weapons, and that we should never resort to such strategic bombing again. That does not mean that we should renounce our right to use A-bombs to destroy an enemy's armies, navies, and airfields, his transportation facilities and his oil wells—in a word, his capacity to make war against us. And as long as we use the A-bomb and the H-bomb only as weapons of tremendous power to destroy by blast and by fire, they are no different from ordinary blockbusters or incendiaries except that they concentrate their power in a small package. Is there any difference, morally speaking, between the use of thousands of blockbusters and tens of thousands of

incendiaries and a weapon that concentrates all their power in one?

Probably the main reason for the confused thinking that has singled out atomic weapons as a greater evil than other weapons of mass destruction has been their radioactivity. But even the A-bombs exploded over Japan were purposely dropped from a height that carried most of the radioactivity away into the upper atmosphere. Nor will the H-bomb, as explained earlier, release great quantities of radioactivity unless it is purposely rigged to do so. We should, therefore, lose nothing and gain much if we renounced the use of A- and H-bombs as radioactive weapons except in retaliation against the use of such weapons on us or our allies. But to renounce their use altogether would be tantamount not only to physical but to spiritual suicide as well, for it would mean condoning the advance of the Red Army.

It has become customary to talk about Russia's atom bomb as though she already was, or soon will be, on a par with us. It is true that eventually she will catch up with us in the development of a large stockpile of her own and in designing more efficient models. But that is only one side of the picture. As of 1950, and for at least until 1952, years that may well be crucial, our superiority in A-bombs will remain unchallenged, not only qualitatively but quantitatively. By that time we shall have greatly increased our lead by the possession

of an effective stockpile of H-bombs. Since Russia cannot build H-bombs at the present stage without sacrificing quantities of plutonium she needs to build up her A-bomb stockpile, she will find herself compelled to build additional plutonium plants, which not only will greatly strain her resources but, more important from our point of view, will gain us additional time.

How many A-bombs can Russia make? Former Secretary of War Henry L. Stimson has told us that the A-bombs we dropped on Japan "were the only ones we had ready." Counting the test bomb at Alamogordo, we had thus produced three bombs by mid-August 1945. This represented the total output of a two-billion-dollar plant, employing three major methods of production, after the plants had been in operation for an average of about six months. In other words, it took our two-billion-dollar plant about six months to produce three A-bombs—a rate of six A-bombs a year.

Now all the evidence at hand, as already pointed out, indicates that, instead of building three different types of plants for producing A-bomb materials, Russia is concentrating entirely on plutonium. Hence, if we assume that she built a plutonium plant equal in output to the total capacity of our wartime uranium and plutonium plants, and further assuming that her methods for producing plutonium are as efficient as ours, the best she could do at present would be at the rate

of six plutonium bombs a year. At this rate she would have about eighteen by the middle of 1952. This would be a sizable stockpile for a nation in sole possession of such a weapon. But would any nation with such a stockpile dare challenge a nation with a stockpile many times bigger, consisting of bombs many times more powerful, and possessing a few hydrogen bombs to boot?

Russia will, no doubt, improve her production methods. But to improve them to the extent of producing, let us say, two bombs per month, she would have to step up her production by four hundred per cent. It is doubtful if such a step-up could be achieved in less than three years.

Then there are other factors to be considered that greatly balance the scales in our favor. To produce plutonium bombs requires tremendous quantities of uranium, something that cannot be conjured up by just dialectic materialism. It so happens that we have access to the only two rich uranium deposits known in the world: the Belgian Congo, and the Great Bear Lake area in Canada. There were no known rich uranium deposits in Russia proper or in the territories of her satellites, with the possible exception of Czechoslovakia. We know this from the fact that she never competed for the world markets for radium, extracted economically only from rich uranium ores, which sold before the war at $25,000 per gram, or at the rate of nearly $12,000,000 a pound. The best evidence,

however, that she does not have at her command rich uranium deposits either in Russia or elsewhere is her ruthless exploitation, at the cost of thousands of human lives, of the depleted uranium mines in the mountains of Saxony, which had long been abandoned by their German owners. The only other known source of pitchblende (the mineral richest in uranium) under Russian control is Joachimsthal (Jachymov) in Bohemia, from which came the first radium sample isolated by Mme Curie about fifty years ago. This mine, too, has been largely depleted, though much of its uranium may possibly be recoverable from the dump-heaps, if they have not in the meantime been disposed of.

Now, every ton of pure uranium metal contains just fourteen pounds of the fissionable element uranium 235. The latter, when split, releases the neutrons that create plutonium out of nonfissionable uranium 238. On the basis of one hundred per cent efficiency, impossible in this operation, the yield of plutonium would thus be fourteen pounds per ton. Since the plutonium must be extracted long before all the U-235 atoms have been split, however, the likelihood is that the yield would be no more than two to four pounds per ton. Russia would thus need tens of thousands of tons of uranium ore to build up a sizable stockpile of A-bombs, and while she may be able to process low-grade ores, it would take her much longer to produce a given quantity of plutonium than it

takes us to produce it from our much richer ores. For example, an ore containing fifty per cent uranium would yield a given quantity of plutonium ten times faster than an ore containing only five per cent, unless a refining plant ten times the size is built at ten times the cost of construction and of operation.

If we take Professor Oliphant's published estimate that the critical mass (that is, the minimum amount) needed for an A-bomb is between 10 and 30 kilograms (22 and 66 pounds), we get a clear picture of the enormous difference there is between rich ores and poor ores for the building up of an A-bomb stockpile, and a further concept of the difficulties that Russia will face in trying to produce an H-bomb.

According to the best available prewar information, the pitchblende of the Belgian Congo has a uranium content as high as 60 to 80 per cent; the Canadian ore yields from 30 to 40 per cent. A conservative estimate would thus place the average uranium content of Belgian and Canadian ores at somewhere around 50 per cent. This contrasts sharply with a prewar figure of around 3 per cent uranium for the pitchblende of Czechoslovakia, and the ore in the mountains of Saxony is of even lower grade.

Hence on the basis of two to four pounds of plutonium per ton of uranium metal, it would require the mining and processing of only 2 tons of Bel-

gian and Canadian ore to obtain that amount as compared with 34 tons for the ore from Czechoslovakia, and a larger amount for the Saxon ore. To make a bomb containing 22 pounds of plutonium would thus require us to mine and process from 11 to 22 tons of ore, whereas Russia would need from 187 to 374 tons. For a bomb requiring 66 pounds, the amount, of course, would be correspondingly tripled, reaching a possible figure of 1,122 tons of ore to produce one A-bomb, as compared with a maximum of no more than 66 tons of the ores available to us. In a state employing slave labor and heedless of the wastage of human lives, the production cost does not count. But even Russia's manpower is not unlimited, and workers removed from other lines of production must inevitably hurt the economy. This factor must put a definite limit to Russia's capacity to produce A-bombs and will make it very difficult, if not impossible, for her to produce a large stockpile in a short time.

When it comes to producing an H-bomb, the disparity between ourselves and Russia assumes astronomical proportions. It takes 80 pounds of uranium 235 to produce one pound of tritium. Since, as we have seen, there are only 14 pounds of U-235 in a ton of natural uranium metal, this means that 5.7 tons of uranium metal would be required, assuming one hundred per cent efficiency of utilization, which is out of the question.

On the basis of figures already given, it can be seen that we would require the mining and processing of only 11.4 tons of ore whereas Russia would have to use as much as 194 tons to produce that single pound of the element which, as the facts cited earlier appear to demonstrate, is vital for the construction of a successful H-bomb.

All these basic facts, never presented before, should convince us that, despite the fact that Russia has exploded her first A-bomb, we still have tremendous advantages over her that she will find extremely difficult to overcome. And we must not forget other advantages on our side that may prove decisive even after Russia succeeds in building up a sizable stockpile. Bombs can be delivered against us at present only by airplane or by submarine. A look at the map will show that whereas the Atlantic and Pacific Oceans stand between us and Russia's nearest bases, we are in a much better position to deliver A-bombs to her vital centers, such as the oil fields in the Caucasus, for example, from bases close by. It is, furthermore, not unreasonable to assume that we, as the most advanced industrial nation in the world, will manage to maintain our lead not only in methods of delivery by superior and faster airplanes, or by guided missiles, but also in the development of radar, sonar, and other detection devices, as well as of superior interceptors and other defensive measures, which would make delivery of A-bombs

against us much more difficult than it would be for us to deliver them against Russia.

For the next three years, it can thus be seen, and possibly for a considerably longer period, the initiative, as far as atomic weapons are concerned, will remain with us. Let us therefore be done with all visionary plans for destroying the shield that now protects civilization as we know it, and proceed to build bigger and better shields, hoping that by our very act of doing so we can prevent the ultimate cataclysm. Right now the outlook is not bright, but our strength, physical and spiritual, should give us faith that the forces of good will prevail in the end over the forces of evil, as they have always done throughout history; that the four freedoms will triumph over the Four Horsemen of the Apocalypse.

V

A PRIMER OF ATOMIC ENERGY

THE material universe, the earth and everything in it, all things living and non-living, the sun and its planets, the stars and the constellations, the galaxies and the supergalaxies, the infinitely large and the infinitesimally small, manifests itself to our senses in two forms, matter and energy. We do not know, and probably never can know, how the material universe began, and whether, indeed, it ever had a beginning, but we do know that it is constantly changing and that it did not always exist in its present form. We also know that in whatever form the universe may have existed, matter and energy have always been inseparable, no energy being possible without matter, and no matter without energy, each being a form of the other.

While we do not know how and when matter and energy came into being, or whether they ever had a beginning in time as we perceive it, we do know that while the relative amounts of matter and energy are constantly changing, the total amount of both, in one form or the other, always remains the same. When a plant grows, energy from the sun, in the form of heat and light, is converted into matter, so that the total weight of the

plant is greater than that of the elementary material constituents, water and carbon-dioxide gas, out of which its substance is built up. When the substance of the plant is again broken up into its original constituents by burning, the residual ashes and gases weigh less than the total weight of the intact plant, the difference corresponding to the amount of matter that had been converted into energy, liberated once again in the form of heat and light.

All energy as we know it manifests itself through motion or change in the physical or chemical state of matter, or both, though these changes and motions may be so slow as to be imperceptible. As the ancient Greek philosopher Heraclitus perceived more than two thousand years ago, all things are in a constant state of flux, this flux being due to an everlasting conversion of matter into energy and energy into matter, everywhere over the vast stretches of the material universe, to its outermost and innermost limits, if any limits there be.

Each manifestation of energy involves either matter in motion or a change in its physical state, which we designate as physical energy; a change in the chemical constitution of matter, which we know as chemical energy; or a combination of the two. Physical energy can be converted into chemical energy and vice versa. For example, heat and light are forms of physical energy, each consisting of a definite band of waves of definite wave

lengths in violent, regular, rhythmic oscillations. A mysterious mechanism in the plant, known as photosynthesis, uses the heat and light energy from the sun to create complex substances, such as sugars, starches, and cellulose, out of simpler substances, such as carbon dioxide and water, converting physical energy, heat, and light into the chemical energy required to hold together the complex substances the plant produces. When we burn the cellulose in the form of wood or coal (coal is petrified wood), the chemical energy is once again converted into physical energy in the form of the original heat and light. As we have seen, the chemical energy stored in the plant manifested itself by an increase in the plant's weight as compared with that of its original constituents. Similarly, the release of the energy manifests itself through a loss in the total weight of the plant's substance.

It can thus be seen that neither matter nor energy can be created. All we can do is to manipulate certain types of matter in a way that liberates whatever energy had been in existence, in one form or another, since the beginning of time. All the energy that we had been using on earth until the advent of the atomic age had originally come from the sun. Coal, as already said, is a petrified plant that had stored up the energy of the sun in the form of chemical energy millions of years ago, before man made his appearance on the earth. Oil

comes from organic matter that also had stored up light and heat from the sun in the form of chemical energy. Water power and wind power are also made possible by the sun's heat, since all water would freeze and no winds would blow were it not for the sun's heat energy keeping the waters flowing and the air moving, the latter by creating differences in the temperature of air masses.

There are two forms of energy that we take advantage of which are not due directly to the sun's radiations—gravitation and magnetism—but the only way we can utilize these is by employing energy derived from the sun's heat. In harnessing Niagara, or in the building of great dams, we utilize the fall of the water because of gravitation. But as I have already pointed out, without the sun's heat water could not flow. To produce electricity we begin with the chemical energy in coal or oil, which is first converted into heat energy, then to mechanical energy, and finally, through the agency of magnetism, into electrical energy.

The radiations of the sun, of the giant stars millions of times larger than the sun, come from an entirely different source, the greatest source of energy in the universe, known as atomic or, more correctly, nuclear energy. But even here the energy comes as the result of the transformation of matter. The difference between nuclear energy and chemical energy is twofold. In chemical energy, such as the burning of coal, the matter lost

in the process comes from the outer shell of the atoms, and the amount of matter lost is so small that it cannot be weighed directly by any human scale or other device. In nuclear energy, on the other hand, the matter lost by being transformed into energy comes from the nucleus, the heavy inner core, of the atom, and the amount of matter lost is millions of times greater than in coal, great enough to be weighed.

An atom is the smallest unit of any of the elements of which the physical universe is constituted. Atoms are so small that if a drop of water were magnified to the size of the earth the atoms in the drop would be smaller than oranges.

The structure of atoms is like that of a minuscule solar system, with a heavy nucleus in the center as the sun, and much smaller bodies revolving around it as the planets. The nucleus is made up of two types of particles: protons, carrying a positive charge of electricity, and neutrons, electrically neutral. The planets revolving about the nucleus are electrons, units of negative electricity, which have a mass about one two-thousandth the mass of the proton or the neutron. The number of protons in the nucleus determines the chemical nature of the element, and also the number of planetary electrons, each proton being electrically balanced by an electron in the atom's outer shells. The total number of protons and neutrons in the nucleus is known as the mass number, which is very close to

the atomic weight of the element but not quite equal. Protons and neutrons are known under the common name "nucleons."

There are two important facts to keep constantly in mind about protons and neutrons. The first is that the two are interchangeable. A proton, under certain conditions, loses its positive charge by emitting a positive electron (positron) and thus becomes a neutron. Similarly, a neutron when agitated, emits a negative electron and becomes a proton. As we shall see, the latter process is taken advantage of in the transmutation of non-fissionable uranium into plutonium, and of thorium into fissionable uranium 233. The transmutation of all other elements, age-old dream of the alchemists, is made possible by the interchangeability of protons into neutrons, and vice versa.

The second all-important fact about protons and neutrons, basic to the understanding of atomic energy, is that each proton and neutron in the nuclei of the elements weighs less than it does in the free state, the loss of weight being equal to the energy binding the nucleons. This loss becomes progressively greater for the elements in the first half of the periodic table, reaching its maximum in the nucleus of silver, element 47. After that the loss gets progressively smaller. Hence, if we were to combine (fuse) two elements in the first half of the periodic table, the protons and the neutrons would lose weight if the newly formed nucleus is

not heavier than that of silver, but would gain weight if the new nucleus thus formed is heavier than silver. The opposite is true with the elements in the second half of the periodic table, the protons and neutrons losing weight when a heavy element is split into two lighter ones, and gaining weight if two elements are fused into one.

Since each loss of mass manifests itself by the release of energy, it can be seen that to obtain energy from the atom's nucleus requires either the fusion of two elements in the first half of the periodic table or the fission of an element in the second half. From a practical point of view, however, fusion is possible only with two isotopes (twins) of hydrogen, at the beginning of the periodic table, while fission is possible only with twins of uranium, U-233 and U-235, and with plutonium, at the lower end of the table.

The diameter of the atom is 100,000 times greater than the diameter of the nucleus. This means that the atom is mostly empty space, the volume of the atom being 500,000 billion times the volume of the nucleus. It can thus be seen that most of the matter in the universe is concentrated in the nuclei of the atoms. The density of matter in the nucleus is such that a dime would weigh 600 million tons if its atoms were as tightly packed as are the protons and neutrons in the nucleus.

The atoms of the elements (of which there are ninety-two in nature, and six more man-made ele-

ments) have twins, triplets, quadruplets, etc., known as isotopes. The nuclei of these twins all contain the same number of protons and hence all have the same chemical properties. They differ, however, in the number of neutrons in their nuclei and hence have different atomic weights. For example, an ordinary hydrogen atom has a nucleus of one proton. The isotope of hydrogen, deuterium, has one proton plus one neutron in its nucleus. It is thus twice as heavy as ordinary hydrogen. The second hydrogen isotope, tritium, has one proton and two neutrons in its nucleus and hence an atomic mass of three. On the other hand, a nucleus containing two protons and one neutron is no longer hydrogen but helium, also of atomic mass three.

There are hundreds of isotopes, some occurring in nature, others produced artificially by shooting atomic bullets, such as neutrons, into the nuclei of the atoms of various elements. A natural isotope of uranium, the ninety-second and last of the natural elements, contains 92 protons and 143 neutrons in its nucleus, hence its name U-235, one of the two atomic-bomb elements. The most common isotope of uranium has 92 protons and 146 neutrons in its nucleus and hence is known as U-238. It is 140 times more plentiful than U-235, but cannot be used for the release of atomic energy.

Atomic, or rather nuclear, energy is the cosmic force that binds together the protons and the neu-

trons in the nucleus. It is a force millions of times greater than the electrical repulsion force existing in the nucleus because of the fact that the protons all have like charges. This force, known as the coulomb force, is tremendous, varying inversely as the square of the distance separating the positively charged particles. Professor Frederick Soddy, the noted English physicist, has figured out that two grams (less than the weight of a dime) of protons placed at the opposite poles of the earth would repel each other with a force of twenty-six tons. Yet the nuclear force is millions of times greater than the coulomb force. This force acts as the cosmic cement that holds the material universe together and is responsible for the great density of matter in the nucleus.

We as yet know very little about the basic nature of this force, but we can measure its magnitude by a famous mathematical equation originally presented by Dr. Einstein in his special theory of relativity in 1905. This formula, one of the great intellectual achievements of man, together with the discovery of the radioactive elements by Henri Becquerel and Pierre and Marie Curie, provided the original clues as well as the key to the discovery and the harnessing of nuclear energy.

Einstein's formula, $E = mc_2$, revealed that matter and energy are two different manifestations of one and the same cosmic entity, instead of being two different entities, as had been generally be-

lieved. It led to the revolutionary concept that matter, instead of being immutable, was energy in a frozen state, while, conversely, energy was matter in a fluid state. The equation revealed that any one gram of matter was the equivalent in ergs (small units of energy) to the square of the velocity of light in centimeters per second—namely, 900 billion billion ergs. In more familiar terms, this means that one gram of matter represents 25,000,000 kilowatt-hours of energy in the frozen state. This equals the energy liberated in the burning of three billion grams (three thousand tons) of coal.

The liberation of energy in any form, chemical, electrical, or nuclear, involves the loss of an equivalent amount of mass, in accordance with the Einstein formula. When 3,000 metric tons of coal are burned to ashes, the residual ashes and the gaseous products weigh one gram less than 3,000 tons; that is, one three-billionth part of the original mass will have been converted into energy. The same is true with the liberation of nuclear energy by the splitting or fusing (as will be explained later) of the nuclei of certain elements. The difference is merely that of magnitude. In the liberation of chemical energy by the burning of coal, the energy comes from a very small loss of mass resulting from the rearrangement of electrons on the surface of the atoms. The nucleus of the coal atoms is not involved in any way, remaining exactly the same as before. The amount of mass lost by the surface

electrons is one thirtieth of one millionth of one per cent.

On the other hand, nuclear energy involves vital changes in the atomic nucleus itself, with a consequent loss of as high as one tenth to nearly eight tenths of one per cent in the original mass of the nuclei. This means that from one to nearly eight grams per thousand grams are liberated in the form of energy, as compared with only one gram in three billion grams liberated in the burning of coal. In other words, the amount of nuclear energy liberated in the transmutation of atomic nuclei is from 3,000,000 to 24,000,000 times as great as the chemical energy released by the burning of an equal amount of coal. In terms of TNT the figure is seven times greater than for coal, as the energy from TNT, while liberated at an explosive rate, is about one seventh the total energy content for an equivalent amount of coal. This means that the nuclear energy from one kilogram of uranium 235, or plutonium, when released at an explosive rate, is equal to the explosion of twenty thousand tons of TNT.

Nuclear energy can be utilized by two diametrically opposed methods. One is fission—the splitting of the nuclei of the heaviest chemical elements into two uneven fragments consisting of nuclei of two lighter elements. The other is fusion—combining, or fusing, two nuclei of the lightest elements into one nucleus of a heavier element. In

both methods the resulting elements are lighter than the original nuclei. The loss of mass in each case manifests itself in the release of enormous amounts of nuclear energy.

When two light atoms are combined to form a heavier atom, the weight of the heavier is less than the total weight of the two light atoms. If the heavier atom could again be split into the two lighter ones, the latter would resume their original weight. As explained before, however, this is true only with the light elements, such as hydrogen, deuterium, and tritium, in the first half of the periodic table of the elements. The opposite is true with the heavier elements of the second half of the periodic table. For example, if krypton and barium, elements 36 and 56, were to be combined to form uranium, element 92, the protons and the neutrons in the uranium nucleus would each weigh about 0.1 per cent more than they weighed in the krypton and barium nuclei. It can thus be seen that energy could be gained either through the loss of mass resulting from the fusion of two light elements, or from the similar loss of mass resulting from the fission of one heavy atom into two lighter ones.

In the fusion of two lighter atoms, the addition of one and one yields less than two, and yet half of two will be more than one. In the case of the heavy elements the addition of one and one yields more than two, yet half of two makes less than

one. This is the seeming paradox of atomic energy.

Three elements are known to be fissionable. Only one of these is found in nature: the uranium isotope 235 (U-235). The other two are man-made. One is plutonium, transmuted by means of neutrons from the nonfissionable U-238, by the addition of one neutron to the 146 present in the nucleus, which leads to the conversion of two of the 147 neutrons into protons, thus creating an element with a nucleus of 94 protons and 145 neutrons. The second man-made element (not yet in wide use, as far as is known) is uranium isotope 233 (92 protons and 141 neutrons), created out of the element thorium (90 protons, 142 neutrons) by the same method used in the production of plutonium.

When the nucleus of any one of these elements is fissioned, each proton and neutron in the two resulting fragments weighs one tenth of one per cent less than it weighed in the original nucleus. For example, if U-235 atoms totaling 1,000 grams in weight are split, the total weight of the fragments will be 999 grams. The one missing gram is liberated in the form of 25,000,000 kilowatt-hours of energy, equivalent in explosive terms to 20,000 tons of TNT. But the original number of protons and neutrons in the 1,000 grams does not change.

The fission process, the equivalent of the "burning" of nuclear fuels, is maintained by what is known as a chain reaction. The bullets used for

splitting are neutrons, which, because they do not have an electric charge, can penetrate the heavily fortified electrical wall surrounding the positively charged nuclei. Just as a coal fire needs oxygen to keep it going, a nuclear fire needs the neutrons to maintain it.

Neutrons do not exist free in nature, all being tightly locked up within the nuclei of atoms. They are liberated, however, from the nuclei of the three fissionable elements by a self-multiplication process in the chain reaction. The process begins when a cosmic ray from outer space, or a stray neutron, strikes one nucleus and splits it. The first atom thus split releases an average of two neutrons, which split two more nuclei, which in turn liberate four more neutrons, and so on. The reaction is so fast that in a short time trillions of neutrons are thus liberated to split trillions of nuclei. As each nucleus is split, it loses mass, which is converted into great energy.

There are two types of chain reactions: controlled and uncontrolled. The controlled reaction is analogous to the burning of gasoline in an automobile engine. The atom-splitting bullets—the neutrons—are first slowed down from speeds of more than ten thousand miles per second to less than one mile per second by being made to pass through a moderator before they reach the atoms at which they are aimed. Neutron-"killers"—materials absorbing neutrons in great numbers—keep

the neutrons liberated at any given time under complete control in a slow but steady nuclear fire.

The uncontrolled chain reaction is one in which there is no moderator—and no neutron-absorbers. It is analogous to the dropping of a match in a gasoline tank. In the uncontrolled chain reaction the fast neutrons, with nothing to slow them down or to devour them, build up by the trillion and quadrillion in a fraction of a millionth of a second. This leads to the splitting of a corresponding number of atoms, resulting in the release of unbelievable quantities of nuclear energy at a tremendously explosive rate. One kilogram of atoms split releases energy equivalent to that of 20,000,000 kilograms (20,000 metric tons) of TNT.

It is the uncontrolled reaction that is employed in the explosion of the atomic bomb. The controlled reaction is expected to be used in the production of vast quantities of industrial power. It is now being employed in the creation of radioactive isotopes, for use in medicine and as the most powerful research tool since the invention of the microscope for probing into the mysteries of nature, living and non-living.

In the controlled reaction the material used is natural uranium, which consists of a mixture of 99.3 per cent U-238 and 0.7 of the fissionable U-235. The neutrons from the U-235 are made to enter the nuclei of U-238 and convert them to the fissionable element plutonium, for use in atomic

bombs. The large quantities of energy liberated by the split U-235 nuclei in the form of heat is at too low a temperature for efficient utilization as power, and is at present wasted. To be used for power, nuclear reactors capable of operating at high temperatures are now being designed.

In the atomic bomb only pure U-235, or plutonium, is used.

In both the controlled and the uncontrolled reactions a minimum amount of material, known as the "critical mass," must be used, as otherwise too many neutrons would escape and the nuclear fire would thus be extinguished, as would an ordinary fire for lack of oxygen. In the atomic bomb two masses, each less than a critical mass, which together equal or exceed it, are brought in contact at a predetermined instant. The uncontrolled reaction then comes automatically, since, in the absence of any control, the neutrons, which cannot escape to the outside, build up at an unbelievable rate.

Whereas the fission process for the release of nuclear energy entails making little ones out of big ones, the fusion process involves making big ones out of little ones. In both processes the products weigh less than the original materials, the loss of mass coming out in the form of energy. According to the generally accepted hypothesis, the fusion process is the one operating in the sun and the stars of the same family. The radiant energy given

off by them, it is believed, is the result of the fusion of four hydrogen atoms into one atom of helium, two of the protons losing their positive charge, thus becoming neutrons. Since a helium atom weighs nearly eight-tenths of one per cent less than the total weight of the four hydrogen atoms, the loss of mass is thus nearly eight times that produced by fission, with a corresponding eightfold increase in the amount of energy liberated. This process, using light hydrogen, is not feasible on earth.

The nuclei of all atoms are thus vast storage depots of cosmic energy. We must think of them as cosmic safe-deposit vaults, in which the Creator of the universe, if you will, deposited at the time of creation most of the energy in the universe for safekeeping. The sun and the other giant stars that give light have, as it were, drawing accounts in this "First National Bank and Trust Company of the Universe," whereas we on this little planet of ours in the cosmic hinterland are much too poor to have such a bank account. So we have been forced all these years we have been on earth to subsist on small handouts from our close neighbor the sun, which squanders millions all over space, but can spare us only nickels, dimes, and quarters (depending on the seasons of the year) for a cup of coffee and a sandwich. We are thus in the true sense of the word cosmic beggars, living off the bounty of a distant relative.

The discovery of fission in 1939 meant that after a million years of exclusive dependence on the sun we had suddenly managed to open a modest drawing account of our own in this bank of the cosmos. We were enabled to do it by stumbling upon two special master keys to five of the cosmic vaults. One of these keys we call fission; the other, which allows us entry into a much richer chamber of the vault, we call fusion. We can get a lot of the stored-up cosmic treasure by using the key to the fission vaults alone, but, as with our terrestrial bank vaults, which generally require two keys before they can be opened, it is not possible to use the key to the fusion vault unless we first use the fission key.

Except for the payment of our heat and light bill, the sun gives us nothing directly in cash. Instead it deposits a very small pittance in the plants, which serve as its major terrestrial banks. The animals then rob the plants and we rob them both. When we eat the food we live by we thus actually eat sunshine.

The sun makes its deposits in the plant through an agent named chlorophyll, the stuff that makes the grass green. Chlorophyll has the uncanny ability to catch sunbeams and to hand them over to the plant. A chemical supergenius inside the plant changes the sunlight energy into chemical energy, just as a bank teller changes bills into silver. With this chemical energy at their disposal, a great

number of devilishly clever chemists in the plants' chemical factory go to work building up many substances to serve as vaults in which to store up a large part of the energy, using only part of it for their own subsistence.

The building materials used by these chemists inside the plants consist mainly of carbon-dioxide gas from the atmosphere, and water from the soil, plus small amounts of minerals either supplied by the good earth or by fertilizers. Carbon dioxide, by the way, composed of one atom of carbon and two atoms of oxygen, is the stuff you exhale. In solid form it is what we know as dry ice, used in efforts to make rain. It is present in the atmosphere in large amounts.

Out of the carbon dioxide and water the chemists in the plants build cellulose, starch, sugar, fat, proteins, vitamins, and scores of other substances, all of which serve as vaults for the sun's rays caught by the chlorophyll. The biggest vaults of all, storing most of the energy, are the cellulose, sugars and starches, fats and proteins. There the stored energy remains until it is released by processes we call burning or digestion, both of which, as we shall see, are different terms for the same chemical reaction. When we burn wood, or the petrified ancient wood we know as coal, we burn largely the cellulose, the chief component of the solid part of plants. When we eat the plants, or the animals in whom the plant tissues are trans-

formed into flesh by the solar energy stored within them, it is the sugars, starches, fats, and proteins that give us the energy we live by.

In the process of burning wood or coal the large cellulose vaults, composed of carbon, hydrogen, and oxygen, are broken up, thus allowing the original solar energy, stored up within them as chemical energy, to escape in the form of heat and light. This is the same heat and light deposited there by the sun many years before—in the case of coal, some two hundred million years back. The process of burning thus transforms the chemical energy in the plants back to its original form of light and radiant heat energy. The complex carbon and hydrogen units in the cellulose are broken up, each freed carbon atom uniting within two oxygen atoms in the air to form carbon dioxide again, while two hydrogen atoms unite with one of oxygen to form water. Thus we see that the cellulose vaults are broken up once more into the original building bricks out of which the chemists in the plants had fashioned them.

When we eat plant or animal food to get the energy to live by, exactly the same process takes place except at a lower temperature. The sunlight deposit vaults of sugar, starch, and fat, also composed, like cellulose, of carbon, hydrogen, and oxygen, are broken up by the digestive system into their component parts, thus allowing the original solar energy stored within them to get free in the

form of chemical energy, which our body uses in its essential processes. Here, too, the end products are carbon dioxide, which we exhale, and water. About half the energy we thus obtain is used by us for the work we do. The other half is used by the body for building up the tissues burned up as part of the regular wear and tear of life.

We thus burn food for our internal energy as we burn cellulose for our external energy. The interesting thing here is that, in both types of burning, fission as well as fusion processes take place. The fission is the splitting of the cellulose, sugar, fats, starches, and proteins into carbon and hydrogen atoms. The fusion part is the union of the carbon and the hydrogen with oxygen to form carbon dioxide and water. The fusion part is just as necessary to release the stored-up solar energy in the wood or coal as is the fission part, for, as everyone knows, unless there is oxygen for the carbon to fuse with, no combustion (burning) can take place and hence no release of energy. The plant vaults would remain closed absolutely tight.

At this point two things become clear. We see, in the first place, that whenever we get any kind of energy in any form we do not in any way create any of it. All we do is merely draw on something that is already stored up; in the case of coal and wood by the sun, in the case of uranium and hydrogen by the same power that created the sun and all energy. We draw water from the spring,

but we do not make the water. On the other hand, we cannot draw the water unless we first find the spring, and even then we cannot draw it unless we have a pitcher.

And we also see, in the second place, that fission and fusion are common everyday phenomena that occur any time you burn anything. Both are essential whenever energy is released, whether it is the chemical energy from coal or the atomic energy from the nuclei of uranium, deuterium, or tritium. When you light a cigarette you employ both fission and fusion or you don't smoke. The first fission and fusion take place in the lighting of the match, the cellulose in the match (whether it is wood or paper) being fissioned (that is, split into its component atoms of carbon and hydrogen). These atoms are then fusioned with the oxygen in the air. The same thing happens when the tobacco catches fire. In each case the fusion with the oxygen makes possible the fission of the cellulose. When we burn U-235, or plutonium, we again get both fission and fusion, except that, instead of oxygen, the nuclei of these elements first fuse with a neutron before they are split apart. Thus we see that the process of burning U-235, or plutonium, requires not only fission but fusion as well, without which they could not burn. This is true also in hydrogen fusion. When you burn deuterium by fusing two deuterons (nuclei of deuterium) to form helium of atomic weight three,

plus a neutron, one of the two deuterons is split in half in the process. Similarly, when you burn tritium by fusion two tritons (nuclei of tritium), one of the tritons splits into two neutrons and a proton, the one proton joining the other triton to form helium of atomic weight four.

Thus we see that fission and fusion are the cosmic firebrands that are always present whenever a fire is lighted, chemical or atomic, whether the fuel is wood, coal, or oil, or uranium, plutonium, deuterium, or tritium. Both, with some variations, are essential for opening the cosmic safe where the energy of the universe is kept in storage. The only reason you get much more energy in the fission and fusion of atomic nuclei is that so much more had been stored in them than in the cellulose vaults on this planet.

The same reason that limits our ability to obtain stored chemical energy to a few fuels also limits our ability to obtain atomic energy. Coal, oil, and wood are the only dividend-paying chemical-energy stocks. Similarly only five elements, uranium 233 and 235, plutonium, deuterium, and tritium are the only dividend-paying atomic-energy stocks, and of these only two (U-235 and deuterium) exist in nature. The other three are re-created from other elements by modern alchemical legerdemain. What is more, we know for a certainty that it will never be possible to obtain atomic energy from any other element, by either fission or fusion.

This should put to rest once and for all the notion of many, including some self-styled scientists, that the explosion of a hydrogen bomb would set the hydrogen in the waters, and the oxygen and the nitrogen in the air, on fire and thus blow up the earth. The energy in common hydrogen is locked up in one of those cosmic vaults which only the sun and the stars that shine can open and which no number of H-bombs could blow apart. Oxygen and nitrogen are locked even for the sun. As for the deuterium in the water, it cannot catch fire unless it is highly concentrated, condensed to its liquid form, and heated to a temperature of several hundred million degrees. Hence all this talk about blowing up the earth is pure moonshine.

But while we know that we have reached the limit of what can be achieved either by fission or by fusion, that by no means justifies the conclusion that we have reached the ultimate in discovery and that fission and fusion are the only possible methods for tapping the energy locked up in matter. We must remember that fifty years ago we did not even suspect that nuclear energy existed and that until 1939 no one, including Dr. Einstein, believed that it would ever become possible to use it on a practical scale. We simply stumbled upon the phenomenon of fission, which in its turn opened the way to fusion.

If science tells us anything at all, it tells us that nature is infinite and that the human mind, driven

by insatiable curiosity and probing ever deeper into nature's mysteries, will inevitably find ever greater treasures, treasures that are at present beyond the utmost stretches of the imagination—as far beyond fission and fusion as these are beyond man's first discovery of how to make a fire by striking a spark with a laboriously made flint. The day may yet come, and past history makes it practically certain that it will come, when man will look upon the discovery of fission and fusion as we look today upon the crudest tools made by primitive man.

A great measure of man's progress has been the result of serendipity, the faculty of making discoveries, by chance or sagacity, of things not sought for. Many an adventure has led man to stumble upon something much better than he originally set out to find. Like Columbus, many an explorer into the realms of the unknown has set his sights on a shorter route to the spices of India only to stumble upon a new continent. Unlike Columbus, however, the explorers in the field of science, instead of being confined to this tiny little earth of ours, have the whole infinite universe as the domain of their adventures, and many a virgin continent, richer by far than any yet discovered, still awaits its Columbus.

Roentgen and Becquerel were exploring what they thought was an untrodden path in the forest and came upon a new road that led their successors to the very citadel of the material universe. Young

Enrico Fermi was curious to find out what would happen if he fired a neutron into the nucleus of uranium, hoping only to create a heavier isotope of uranium, or at best a new element. His rather modest goal led five years later to the fission of uranium, and in another six years to the atomic bomb.

Yet, as we have seen, in both fission and fusion only a very small fraction of the mass of the protons and neutrons in the nuclei of the elements used is liberated in the form of energy, while 99.3 to 99.9 per cent of their substance remains in the form of matter. We know of no process in nature which converts 100 per cent of the matter in protons and neutrons into energy, but scientists are already talking about finding means for bringing about such a conversion. They are seeking clues for such a process in the mysterious cosmic rays that bombard the earth from outer space with energies billions of times greater than those released by fission or fusion, great enough to smash atoms of oxygen or nitrogen, or whatever other atoms they happen to hit in the upper atmosphere, into their component protons and neutrons. Luckily, their number is small and most of their energy is spent long before they reach sea level.

But we have already learned how to create secondary cosmic-ray particles of relatively low energies (350,000,000 electron-volts) with our giant cyclotrons. The creation of these particles, known as mesons, which are believed to be the cosmic

cement responsible for the nuclear forces, represents the actual conversion of energy into matter. This is the exact reverse of the process taking place in fission and fusion, in which, as we have seen, matter is converted into energy. And we are now about to complete multibillion-volt atom-smashers that will hurl atomic bullets of energies of from three to ten billion volts at the nuclei of atoms. With these gigantic machines, known as the cosmotron (at the Brookhaven National Laboratory of the Atomic Energy Commission) and the bevatron (at the University of California), we shall be able to smash nuclei into their individual component protons and neutrons and thus get a much more intimate glimpse of the forces that hold the nuclei together. What is more, instead of creating only mesons, particles with only 300 electron masses, we shall be able for the first time to convert energy into protons and neutrons, duplicating, as far as is known, an act of creation that has not taken place since the beginning of the universe. Man at last will be creating the very building blocks out of which the universe is made, as well as the cosmic cement that holds them together.

What new continents will our first glimpse into the mechanism of the very act of creation of matter out of energy reveal? What new secrets will be uncovered before the dazzled eyes and mind of man when he takes the nucleus of the atom completely apart at last? Not even Einstein could tell

us. But, as Omar Khayyám divined, "a single Alif" may provide "the clue" that, could we but find it, leads "to the Treasure-House, and peradventure to the Master too." The fact is that we already have opened the door to the anteroom of the treasure-house, and we are about to unlock the door to one of its inner chambers. What shall we find there? No one as yet knows. But we do know that every door man has opened so far has led to riches beyond his wildest dreams, each new door bringing greater rewards than the one before. On the other hand, we also know that the treasure-house has many mansions, and that no matter how many chambers he may enter, he will always find new doors to unlock. For we have learned that the solution of any one secret always opens up a thousand new mysteries.

We also have learned, to our sorrow, that any new insight gained into nature's laws and forces can be used for great good and for equally great evil. The greater the insight, the greater the potentialities for good or evil. The new knowledge he is about to gain by his deeper insight into the heart of matter, and by his ability to create it out of energy, may offer man the means to make himself complete master of the world he lives in. It is equally true, alas, that he could use it to destroy that world even more thoroughly than with the hydrogen bomb.

As already stated, scientists are even now dis-

cussing the possibility of finding means for the complete annihilation of matter by the conversion of the entire mass of protons and neutrons into energy, instead of only 0.1 to 0.7 per cent. And while the total annihilation of protons and neutrons still seems highly speculative, we already know that such a process actually does take place in the realm of the electron. This is the phenomenon already achieved numerous times on a small scale in the laboratory, in which a positive electron (positron) and an electron with a negative charge completely destroy each other, their entire mass being converted into energy. Luckily, this is at present only a laboratory experiment, in which each positron must be individually produced, since there are hardly any positive electrons in our part of the universe. But suppose the new knowledge we are about to pry loose from the inner citadel of matter reveals to us a new process, at present not even suspected, that would release positrons in large numbers, just as the fission and fusion processes made possible for the first time the liberation of large quantities of neutrons. Such an eventuality, by no means beyond the realm of the possible, would open potentialities of horror alongside which those of the H-bomb, even the rigged one, would be puny. For any process that would release large numbers of positrons in the atmosphere, in a chain reaction similar to the one now liberating neutrons, may envelop the earth in one deadly flash of radio-

active lightning that would instantly kill all sensate things. And although this is admittedly purely speculative, no one dare say that such a discovery will not be made, not when one remembers how remote and unlikely a process such as fission seemed to be just before it was made.

Though many of the great discoveries came about as the result of chance, they came because, as Pasteur said, "chance favors the prepared mind." Actually they came largely through the intellectual synthesis of what had originally appeared as unrelated phenomena or concepts. When Faraday discovered the principle of electromagnetic induction, he established for the first time that electricity and magnetism, looked upon since prehistoric times as two separate and distinct phenomena, were actually only two aspects of one basic natural force, which we know today as electromagnetism. This great intellectual synthesis led directly to the age of electricity and all its wonders. About thirty years later the great Scottish physicist James Clerk Maxwell demonstrated that electromagnetic action traveled through space in the form of transverse waves similar to those of light and having the same velocity. This revealed the existence in nature of electromagnetic waves, better known to us today as radio waves. About a quarter century later the great German-Jewish physicist Heinrich Hertz not only produced these electromagnetic waves but showed that they are propagated just as waves of

light are, possessing all other properties of light, such as reflection, refraction, and polarization. This led directly to wireless telegraphy and telephony, radio and television, radiophotography and radar.

When Einstein, in his special theory of relativity of 1905, united matter and energy in one basic cosmic entity, the road was opened to the atomic age. Yet Einstein was never satisfied and has devoted more than forty-five years of his life to the search for a greater, all-embracing unity underlying the great diversity of natural phenomena. In his general theory of relativity of 1915 he formulated a concept that encompasses the universal law of gravitation in his earlier synthesis of space and time, of which matter and energy were an integral part. This synthesis, wrote Bertrand Russell in 1924, "is probably the greatest synthetic achievement of the human intellect up to the present time. It sums up the mathematical and physical labors of more than two thousand years. Pure geometry from Pythagoras to Riemann, the dynamics and astronomy of Galileo and Newton, the theory of electromagnetism as it resulted from the researches of Faraday, Maxwell, and their successors, all are absorbed, with the necessary modifications, in the theories of Einstein, Weyl, and Eddington.

"So comprehensive a synthesis," he continued, "might have represented a dead end, leading to no further progress for a long time. Fortunately, at

this moment quantum theory [the theory applying to the forces within the atom] has appeared, with a new set of facts outside the scope of relativity physics [which applies to the forces governing the cosmos at large]. This has saved us, in the nick of time, from the danger of supposing that we know everything."

Yet Einstein, working away in majestic solitude, has been trying all these years to construct a vast intellectual edifice that would embrace all the laws of the cosmos known so far, including the quantum, in one fundamental concept, which he designates as a "unified field theory." Early in 1950 he published the results of his arduous labors since 1915. This he regards as the crowning achievement of his life's work, a unified theory that bridges the vast gulf that had existed between relativity and quantum, between the infinite universe of the stars and galaxies and the equally infinite universe within the nucleus of the atom. If he is right, and he has always been right before, his latest contribution will prove to be a greater synthetic achievement of the human intellect than ever before, embracing space and time, matter and energy, gravitation and electromagnetism, as well as the nuclear forces within the atom, in one all-encompassing concept. In due time this concept should lead to new revelations of nature's mysteries, and to triumphs even greater than those which followed as

a direct consequence of all earlier intellectual syntheses.

If the synthesis of matter and energy led to the atomic age, what may we expect of the latest, all-inclusive synthesis? When Einstein was asked about it he replied: "Come back in twenty years!" which happens to coincide with the end of the hundred-year period recorded by the brothers Goncourt: God swinging a bunch of keys, and saying to humanity: "Closing time, gentlemen!"

The search for new intellectual syntheses goes on, and no doubt new relationships between the diverse phenomena of nature will be found, regardless of whether Einstein's latest theory stands or falls in the light of further discovery. Physicists, for example, are speculating about a fundamental relationship between time and the electronic charge, one of the most basic units of nature, and there are those who believe that this relationship will turn out to be much more fundamental than that between matter and energy. Should this be found to be true, then the discovery of the relationship between time and charge may lead to finding a way for starting a self-multiplying positron-electron chain reaction, just as the relationship between matter and energy led inevitably to the self-multiplying chain reaction with neutrons. If this comes about, then closing time will come much closer.

Yet the sound of the swinging keys need not necessarily mean closing time for man at the twilight of his day on this planet. It could also mean the opening of gates at a new dawn, to a new earth—and a new heaven.

APPENDIX

THE HYDROGEN BOMB AND INTERNATIONAL CONTROL

In the fall of 1949 Senator McMahon directed the staff of the Joint Congressional Committee on Atomic Energy to study the hydrogen bomb in relation to international control of atomic energy. The material in the following pages, with the exception of the comments in Appendix D, was prepared by the staff at the chairman's request to assist the joint committee in considering the problem.

It is my belief that this valuable material, until now unavailable in such excellent summary form, will also assist Americans in general in considering this vital problem. Readers of this volume should find it helpful in arriving at conclusions of their own, particularly in the light of the facts and discussion presented in Chapters III and IV. I further believe that a careful perusal of the following material will lend strong support to my view that the international control of atomic weapons, as envisaged in the majority plan of the United Nations,—the only plan that may give assurance against a surprise atomic attack—had become wholly impractical even before the entry of the H-bomb into the picture, and that the imminent development of the H-bomb has made it so unworkable that any further plan to revive it would be futile.

This material makes it clear (a) that Russia never had any intention of reaching any agreement on international control and had set out to sabotage any plan from the very beginning; and (b) that no plan, no matter how foolproof, could hope to succeed in the absence of complete mutual trust and confidence. Events in Korea, I am convinced, have driven the last nail into the coffin of the UN control plan.

A

SIGNIFICANT EVENTS IN THE HISTORY OF INTERNATIONAL CONTROL OF ATOMIC WEAPONS

May 1945: Secretary of War Stimson appoints interim Committee to study problem of atomic energy.

August 6, 1945: Hiroshima.

October 3, 1945: President's message to Congress outlines necessity for international control of atomic energy and proposes conversations with Canada and United Kingdom.

November 15, 1945: Three-nation agreed declaration on atomic energy (Truman-Attlee-King declaration). Calls for United Nations Commission to make proposals for international control plan. Proposals should provide safeguards "by way of *inspection and other means.*" (Wherever used in the following pages, italics are supplied.)

December 27, 1945: U.S.–U.K.–U.S.S.R. Foreign Minister communiqué on results of Moscow Conference. Proposes that Canada, China, and France join with Big Three in sponsoring resolution calling for United Nations Atomic Energy Commission with terms of reference stipulated in Truman-Attlee-King declaration.

January 24, 1946: General Assembly resolution establishing United Nations Commission on Atomic Energy. Composed of members of Security Council plus Canada.

March 28, 1946: Acheson-Lilienthal report. Urges that mines and "dangerous" atomic-energy facilities be put under *international ownership* and *management* of Atomic Development Authority. Additional safeguards in the form of *inspection*. Nations to operate "safe" plants under ADA license. Plants to be distributed among nations in keeping with *strategic balance*. Control plan to be implemented by *stages*.

June 14, 1946: Baruch proposals to United Nations. Closely follow Acheson-Lilienthal recommendations. Ask "condign punishment," for violations, and request agreement that UN Charter *veto* clause not apply to sanctions for stipulated violations of atomic-energy treaty.

June 19, 1946: Soviet Union counterproposals. Demand prohibition of atomic weapons and destruction of existing stockpiles *before* international control plan is negotiated. Soviet proposals provide no safeguards against evasion.

December 31, 1946: First Report of UNAEC. Incorporates essential features of Baruch proposals into statement of principles for plan for international control of atomic energy. Adopted 10 to 0, with U.S.S.R. and Poland abstaining.

June 11, 1947: U.S.S.R. control proposals. Soviets assent to *periodic inspection*, but this would apply only to *declared* plants.

August 11, 1947: Soviets consent in principle to concept of *quotas*.

September 11, 1947: Second Report of UNAEC. Outlines powers, functions, and limitations thereon of

any international agency in implementing effective control plan.

May 17, 1948: Third Report of UNAEC. Reports impasse because Soviets refuse to accept majority plan and persist in refusing to put forward effective proposals of their own. Concludes that further work in UNAEC is fruitless until Soviet cooperation in broader fields of policy is secured. Recommends that Commission's work be suspended until sponsoring powers find that basis for agreement exists.

September 25, 1948: Soviets modify position by asking that conventions for prohibition of atomic weapons and for international control go into effect simultaneously.

November 4, 1948: By vote of 40 to 6, UN General Assembly endorses majority control plan. Calls upon UNAEC to continue work and requests that sponsoring powers consult to explore possible basis of agreement.

August 9, 1949: First meeting of sponsoring powers of UNAEC.

September 23, 1949: President Truman's announcement of Soviet atomic explosion.

October 25, 1949: Canada, China, France, United Kingdom, United States statement reveals Soviet attitude still prevents agreement.

November 23, 1949: General Assembly resolution calls upon sponsoring powers to continue consultations.

November 23, 1949: Soviets reverse position on quotas, abandoning previous assent in principle.

January 19, 1950: U.S.S.R. walks out of sponsoring powers consultations over China recognition issue.

January 31, 1950: President Truman announces that United States will proceed with development of hydrogen bomb.

B

THE INTERNATIONAL CONTROL OF ATOMIC WEAPONS: A BRIEF HISTORY OF PROPOSALS AND NEGOTIATIONS

Early steps looking toward international control

Even before the test explosion at Alamagordo, N. Mex., had ushered in the atomic age, the United States Government was studying methods of making atomic energy a socially constructive force.

In May 1945 an Interim Committee appointed by Secretary of War Stimson commenced investigating the problem. The Committee recognized "that the means of producing the atomic bomb would not forever remain the exclusive property of the United States. . . ." Therefore, "Secretary of War Stimson was one of the first to recommend a policy of international supervision and control of the entire field of atomic energy. . . ."

When on August 6, 1945, President Truman made the first public statement on the atomic bomb, he made clear that "under present circumstances it is not intended to divulge the technical process of production or all the military application, pending further examination of possible methods of protecting us and the rest of the world from the danger of sudden destruction." He assured the American people that he

would "make further recommendations to the Congress as to how atomic power can become a powerful and forceful influence toward the maintenance of world peace."

The President's recommendations were transmitted to the Congress on October 3, 1945. He spoke of the necessity for "international arrangements looking, if possible, to the renunciation of the use and development of the atomic bomb, and directing . . . atomic energy . . . toward peaceful and humanitarian ends." So great a challenge could not await the full development of the United Nations. The President, therefore, proposed initiating discussions "first with our associates in this discovery, Great Britain and Canada, and then with other nations. . . ."

The Truman-Attlee-King declaration

In the three-nations agreed declaration of November 15, 1945—frequently called the Truman-Atlee-King declaration—was recorded the concerted objectives of the three nations that had developed the atomic bomb.

According to the declaration, any international arrangements should have a dual goal: Preventing the use of atomic energy for destructive purposes, and promoting its use for peaceful and humanitarian ends. To reach these objectives, the signatory nations proposed a United Nations Commission empowered to make recommendations to the parent body. It was asked that the Commission make specific proposals "for effective safeguards by way of inspection and other means to protect states against the hazards of

violations and evasions." It was further suggested that the Commission's work "proceed by separate stages, the successful completion of each of which will develop the necessary confidence of the world before the next stage is undertaken."

Contained in the agreed declaration was the genesis of the basic feature of the control proposals subsequently advanced by the United States, and accepted by a large majority of the United Nations: safeguards through inspection and *other means.* It was recognized even at this early date that "effective, reciprocal, and enforceable safeguards" against evasion represented the minimum prerequisite of a satisfactory international arrangement.

At the Moscow meeting of the Council of Foreign Ministers, held in December 1945, the Truman-Attlee-King proposals received the Soviet Union's endorsement. The United States, Great Britain, and the Soviet Union agreed to invite Canada, China, and France to join with them in sponsoring a resolution calling for a United Nations Atomic Energy Commission. Such a Commission would consist of the 11 members of the Security Council plus Canada when that state was not sitting on the Council. It is noteworthy that the Commission's proposed terms of reference were exactly those suggested by the Truman-Attlee-King declaration.

In its first substantive resolution, the United Nations General Assembly unanimously adopted the recommendations of the Moscow Conference and established the United Nations Commission on Atomic Energy on January 24, 1946.

The Acheson-Lilienthal report

In order to inquire into the nature of the "effective, reciprocal, and enforceable safeguards" called for in the Truman-Attlee-King declaration, Secretary of State Byrnes in January 1946 appointed a Committee headed by Under Secretary of State Dean Acheson. The Committee in turn enlisted the aid of a Board of Consultants under the chairmanship of David Lilienthal.

The findings of the two groups were made public on March 28, 1946, in the Report on the International Control of Atomic Energy, commonly called the Acheson-Lilienthal report. It was advanced "not as a final plan but as a place to begin, a foundation on which to build."

The report concluded that no security against atomic attack could be found in an agreement that merely "outlawed" these weapons. Nor was it considered feasible to control atomic energy "only by a system which relies on inspection and similar police-like methods." Instead, inspection must be supplemented by *international ownership and management* of raw materials and key installations. "Dangerous" operations—those of potential military consequence—would be carried out by an Atomic Development Authority, an international agency under the United Nations. Only "safe" activities—those of no military importance—would be conducted by the individual nations, under licenses from the Atomic Development Authority. Any plan finally agreed upon would

be implemented by *stages* with the United States progressively transferring its fund of theoretical and technological knowledge to an international authority as safeguards were put into effect.

The report amplified the Truman-Attlee-King proposals in two important respects.

First, it stated that international ownership—not specifically mentioned in the earlier declaration—was a necessary adjunct of international inspection. Second, it advanced the concept of "strategic balance" or "quotas." The Report held that an acceptable plan must be "such that if it fails or the whole international situation collapses, any nations such as the United States will still be in a relatively secure position, compared to any other nation." To help attain this end, it was proposed that the Atomic Development Authority's stock piles and plants be well distributed geographically.

The Baruch proposals to the United Nations

Less than 3 months after the publication of the Acheson-Lilienthal report, the United States Government gave the world its proposals for the international control of atomic energy. On June 14, 1946, Bernard Baruch presented them to the United Nations Atomic Energy Commission "as a basis for beginning our discussion."

Mr. Baruch stated that:

When an adequate system for control of atomic energy, including the renunciation of the bomb as a weapon, has

been agreed upon and put into effective operation and condign punishments set up for violations of the rules of control which are to be stigmatized as international crimes, we propose that:

1. manufacture of atomic bombs shall stop;
2. existing bombs shall be disposed of pursuant to the terms of the treaty; and
3. the Authority shall be in possession of full information as to the know-how for the production of atomic energy.

The methods suggested for achieving international control were the following:

The United States proposes the creation of an International Atomic Development Authority, to which should be entrusted all phases of the development and use of atomic energy, starting with the raw material and including—

1. Managerial control or ownership of all atomic energy activities potentially dangerous to world security.
2. Power to control, inspect, and license all other atomic activities.
3. The duty of fostering the beneficial uses of atomic energy.
4. Research and development responsibilities of an affirmative character intended to put the Authority in the forefront of atomic knowledge and thus to enable it to comprehend, and therefore to detect—misuse of atomic energy. To be effective, the Authority must itself be the world's leader in the field of atomic knowledge and development and thus supplement its legal authority with the great power inherent in possession of leadership in knowledge.

These proposals represented a broadening—rather than essential modification—of the Acheson-Lilienthal recommendations. The additional features concerned (1) *condign punishment,* and (2) the so-called power of veto of the United Nations Charter.

Whereas the Acheson-Lilienthal report had not dealt with the subject of sanctions, Mr. Baruch held that a realistic agreement must provide for penalties "of as severe a nature as the nations may wish and as immediate and certain in their execution as possible. . . ." Such "condign punishment" would be meted out if *previously stipulated* violations of a control plan occurred.

This problem, Mr. Baruch stated, was intimately related with the veto provisions of the United Nations Charter. Under the Charter, sanctions can be invoked only with the concurrence of the five permanent members of the Security Council, i.e., China, France, United Kingdom, United States, and the Soviet Union. Mr. Baruch maintained, however, that "there must be no veto to protect those who violate their solemn agreements not to develop or use atomic energy for destructive purposes. . . . The bomb does not wait on debate." He pointed out that the United States was "concerned here with the veto power only as it affects this particular problem."

A United States memorandum of July 12, 1946, stressed that "Voluntary relinquishment of the veto on questions relating to a specific weapon previously outlawed by unanimous agreement because of its uniquely destructive character, in no wise involves any

compromise of the principle of unanimity of action as applied to general problems or to particular situations not foreseeable and therefore not susceptible of advance unanimous agreement."

The first Soviet proposals—Gromyko's statement of June 19, 1946

A week after the American plans were put forward, the Soviet Union announced its own proposals. They were marked chiefly by Soviet insistence that the United States agree to stop the production of atomic weapons and destroy existing bombs *before* international control arrangements were negotiated.

Although they called for "an international convention for outlawing weapons based on the use of atomic energy," the Soviet proposals did not provide "effective safeguards by way of inspection and other means to protect complying states against the hazards of violations and evasions." They proposed that the "rule of unanimity" in the Security Council apply to atomic-energy matters. Hence if one of the permanent members of the Security Council or a friend violated a control scheme, the other members of the United Nations would have no legal means, under the Charter, of invoking sanctions against it.

Throughout 1946 the United Nations Atomic Energy Commission continued its investigations of the control problem. On December 31, 1946, the Commission issued its *First Report*. It revealed that the essential features of the Baruch proposals had won the support of all the members of the Commission except the Soviet Union and Poland.

The Soviet Proposals of June 11, 1947

A year after it suggested a convention for "outlawing" atomic weapons, the Soviet Union came forward with a set of control proposals.

A chief point of interest in the plan was the fact that the Soviets now assented to "*periodic* inspection of facilities for mining and production of atomic materials" by an international inspectorate. In answer to a United Kingdom inquiry, however, the Russians stated that "normally, inspectors will visit only *declared* plants"—with this supplemented by special investigations when there were "grounds for suspicion" of violation of the convention for the prohibition of atomic weapons. The power of the Control Commission would be further limited to making recommendations to governments and to the Security Council. On other matters that separated the Soviet Union from the majority position—such as international ownership and management, and the veto question—there was no change in the Russian position.

The subsequent half-year brought one sign of a further modification of the U.S.S.R. stand. On August 11, 1947, Mr. Gromyko seemingly brought the Soviets closer to the majority position by agreeing that "the idea of quotas deserves attention and serious consideration by the Atomic Energy Commission. . . ."

The Second and Third Reports of the United Nations Atomic Energy Commission—September 11, 1947, and May 17, 1948

The *Second Report* of the Atomic Energy Commission spelled out in detail the precise powers and

functions and the limitations thereon of any international agency in implementing an effective control plan. When the *Report* was approved by the General Assembly by a vote of 40 to 6, the plan developed in the UNAEC became a world plan—to which only the Soviet Union and her satellites took exception.

By the spring of 1948 the UNAEC became convinced that the Soviet Union's refusal to accept any plan that met the technical requirements of controlling atomic energy was symptomatic of broader differences which made further negotiations on the Commission level fruitless.

The *Third Report* stated that "the majority of the Commission has been unable to secure the agreement of the Soviet Union to even those elements of effective control from the technical point of view, let alone their acceptance of the nature and extent of participation in the world community required of all nations in this field. . . ."

It appeared to the Commission that the atomic deadlock was but one manifestation of the more widespread dispute between the Soviet Union and the rest of the world. In view of this, the Commission majority recommended that negotiations in the Commission be suspended until the permanent members of the UNAEC found that "there exists a basis for agreement on the international control of atomic energy. . . ."

The following were regarded as the basic considerations which, even on a technical level, made the U.S.S.R. position untenable:

I. The powers provided for the International Control Commission by the Soviet Union proposals, confined as they are to *periodic inspection* and *special investigations,* are insufficient to guarantee against the diversion of dangerous materials from known atomic facilities, and do not provide the means to detect secret activities.

II. Except by recommendations to the Security Council of the United Nations, the International Control Commission has no powers to enforce either its own decisions or the terms of the convention or conventions on control.

III. The Soviet Union Government insists that the convention establishing a system of control, even so limited as that contained in the Soviet Union proposals, can be concluded only *after* a convention providing for the prohibition of atomic weapons and the destruction of existing atomic weapons has been "signed, ratified, and put into effect." [Italics in original.]

The Commission's work had come to a standstill.

Atomic energy negotiations since 1948

Meeting in Paris in the fall of 1948 the General Assembly, by a vote of 40 to 6, approved the general findings and recommendations of the FIRST REPORT and the specific proposals of part II of the SECOND REPORT "as constituting the necessary basis for the establishing of an effective system of international control of atomic energy." However, it called upon the UNAEC to continue its work and to study such subjects as it deemed "practicable and useful," and asked that the permanent members of the Commission "consult in order to determine if there exists a basis for agreement. . . ." The permanent members were requested

to transmit the results of their consultations to the General Assembly.

In the meanwhile, the Soviet Union had served notice of what appeared to be a significant change in its position. In a draft resolution dated September 25, 1948, the Soviets proposed—

> To elaborate draft conventions for the banning of atomic weapons and conventions for the establishment of international effective control over atomic energy, taking into account that the convention for the banning of atomic weapons and the convention for the establishment of international control over atomic energy must be signed and implemented and entered into force *simultaneously.*

It was the last word of this resolution that marked a change in the U.S.S.R. stand. Previously, the Soviets had demanded that atomic weapons production be prohibited and stock piles be destroyed *before* a control plan was discussed.

Nonetheless, the new Soviet proposal gave no indication that the Soviets would accede to what the majority regard as an *effective* control plan. Furthermore, the proposal for simultaneous prohibition and control was considered to be physically impossible to implement. "The development of atomic energy is the world's newest industry, and already is one of the most complicated. It would not be reasonable to assume that any effective system of control could be introduced and enforced overnight. Control and prohibition must, therefore, go into effect over a period of time and by a series of stages."

The record of negotiations from the fall of 1948 to the present is largely one of inaction.

On September 23, 1949, President Truman announced that an atomic explosion had occurred in the Soviet Union. One month later, the sponsoring powers of the UNAEC revealed that the consultations between them "had not yet succeeded in bringing about agreement between the U.S.S.R. and the other five powers."

Despite this, the General Assembly, on November 23, 1949, asked that the permanent members of the Commission continue their consultations and keep the Commission and the General Assembly informed of their work. On the same day, Vishinsky revealed that the Soviets no longer entertained favorably the principle of quotas.

On January 19, 1950, consultations came to an end when the Soviet Union withdrew from the discussions over the question of recognition of the Chinese Government.

C

THE ATOMIC IMPASSE

Regarded in fundamental terms, the deadlock in international control negotiations reflects diametrically opposed notions of the responsibilities of individual nations in a world of atomic energy.

All nations except the Soviet Union and her satellites "put world security first, and are prepared to accept innovations in traditional concepts of international cooperation, national sovereignty, and economic organization where these are necessary for security. The government of the U.S.S.R. puts its sovereignty first and is unwilling to accept measures which may impinge upon or interfere with its rigid exercise of unimpeded state sovereignty."

This basic variance in the objectives of the Soviet Union and the other members of the United Nations is mirrored in the majority and minority control proposals.

The specific differences in the two plans may be summarized as follows:

International Inspection

United Nations.—Complete and continuing inspection by international personnel, including aerial and ground surveys, and inspection of atomic facilities.

Soviet Union.—Periodic inspection of declared plants. Special investigations when there exist "grounds

for suspicion"—not that the control agreement has been violated—but that the convention outlawing atomic weapons has been violated. (This could mean that only if a nation were subjected to surprise atomic attack would the necessary "grounds for suspicion" enter into existence.)

International ownership and management

United Nations.—International ownership or management of dangerous facilities and international ownership of source materials and their fissionable derivatives—in order to prevent diversion of such material from existing plants.

Soviet Union.—Complete opposition to international ownership or management provisions.

Strategic balance (quotas)

United Nations.—National quotas to be incorporated into international control treaty.

Soviet Union.—Sees in quotas an instrument for "American domination."

Sanctions

United Nations.—No veto to protect those who violate stipulated provisions of international agreement.

Soviet Union.—All decisions require unanimous consent of permanent members of Security Council.

The permanent members of the UNAEC have summarized the differences between the Soviet plan and the world plan in the following fashion:

"The Soviet Union proposes that nations should continue to own explosive atomic materials.

"The other five Powers feel that under such conditions there would be no effective protection against the sudden use of these materials as atomic weapons.

"The Soviet Union proposes that nations continue, as at present, to own, operate, and manage facilities making or using dangerous quantities of such materials.

"The other five Powers believe that, under such conditions, it would be impossible to detect or prevent the diversion of such materials for use in atomic weapons.

"The Soviet Union proposes a system of control depending on periodic inspection of facilities the existence of which the national government concerned reports to the international agency, supplemented by special investigations on suspicion of treaty violations.

"The other five Powers believe that periodic inspection would not prevent the diversion of dangerous materials and that the special investigations envisaged would be wholly insufficient to prevent clandestine activities."

D

POSSIBLE QUESTIONS REGARDING H-BOMBS AND INTERNATIONAL CONTROL [1]

The answers to many of the questions which follow are obvious. The answer to other questions are less obvious. Each question has been selected to suggest and to illustrate the kind of problem which may be involved, whether easy or difficult of solution. It should be emphasized that the original United States proposals and the existing United Nations plan foresee and carefully take into account the possibility of an H-bomb, as evidenced by the language they contain. The same is true of the McMahon Act for domestic control of atomic energy within the United States.

1. Is the hydrogen bomb a more or less important weapon than the atomic bomb? Might hydrogen bombs prove to be decisive in war, or has their significance been exaggerated?

Dr. Harold Urey, a Nobel Prize winner in [chemistry], has suggested that the H-bomb would be militarily decisive; Dr. Hans Bethe, [and other noted physicists, have] indicated that the step from A-bombs to H-bombs is as great as the original step from con-

[1] All material in this appendix, except those paragraphs headed "Author's Comments," has been prepared by the staff of the Joint Committee on Atomic Energy.

ventional to atomic explosives. However, Dr. Robert F. Bacher, a former AEC Commissioner, states that—

> while it [the H-bomb] is a terrible weapon, its military effectiveness seems to have been grossly overrated in the minds of laymen.

Some of the questions which may bear upon this difference of opinion are as follows:

(1) *Shock effect.*—To what extent do H-bombs excel A-bombs in permitting a highly destructive attack to be compressed in time?

(2) *Comparative numbers.*—What quantity of A-bombs are required to do the same job as a given number of H-bombs?

(3) *Neutron economy.*—How much fissionable material for A-bombs is sacrificed by using the neutrons available in reactors for making H-bomb materials?

(4) *Deliverability.*—Under various combat conditions, is the delivery of H-bombs cheaper and surer than delivery of an "equivalent" number of A-bombs?

(5) *Aiming accuracy.*—How superior is a weapon which need strike only within a number of miles in order to destroy its target over one which must strike within 1 or 2 miles?

(6) *Psychology.*—As compared with the A-bomb, to what extent might the H-bomb impair an enemy's will to resist and accelerate recognition of defeat?

(7) *Tactical employment.*—What is the relative value of A-bombs and H-bombs in tactical situations—when used against troops in the field, guerrilla fighters, forces preparing for amphibious invasion, a

fleet, a string of air strips or submarine bases, atomic facilities, underground installations, etc.?

(8) *Definition of "military effectiveness."*—Would the use of H-bombs to destroy large urban centers containing no armaments plants have no "military effectiveness," or would such destruction aid the attacker and therefore represent "militarily effective" use of the weapon? Is it possible to distinguish, in an era of total war, between "military" and "nonmilitary" targets?

AUTHOR'S COMMENT

The answer to (1) becomes obvious in light of the answers to (2), (3), (4), (5), and (6), all of which must be considered together. We know that a standard H-bomb would be the equal to ten nominal A-bombs in its power to destroy by blast and to as many as thirty A-bombs in its incendiary effects. In terms of total area, the H-bomb can destroy by blast an area of more than 300 square miles, as compared with an area of only ten square miles for the nominal A-bomb, and more than 1,200 square miles by fire and burns, as compared with only four square miles for the early A-bomb model. As for neutron economy, we have seen that this vast increase in power could be achieved at a cost in fissionable A-bomb material possibly as low as one twelfth, and no higher, at the most, than the plutonium required (according to Professor Oliphant's estimate) for just one A-bomb. It thus becomes obvious that such a weapon not only is much cheaper, in terms of destruction and cost of materials, than the conventional A-bomb, but is much more

easily and safely delivered, since it would still be highly effective as a blasting weapon if exploded more than five miles from its target, while as an incendiary it would still be highly effective as far as fifteen miles away. Hence there can be no question that H-bombs vastly excel A-bombs in permitting a highly destructive attack to be compressed in time, and that its psychological effect in impairing an enemy's will to resist is also incalculably greater.

Its vastly greater range of destructiveness, its economy of material, and its surer delivery also make the H-bomb vastly superior to the A-bomb as a tactical weapon. Neither the H-bomb nor the A-bomb appears to be practical for use against guerrilla fighters, except possibly as a threat.

As already discussed at length in Chapter III, there could be no possible justification, on moral as well as military grounds, for using the H-bomb as a strategic weapon to destroy large urban centers, especially those containing no armaments plants, except in retaliation for such use against us or our allies.

2. If the H-bomb is deemed to be decisive or far more dangerous than the A-bomb, should international control of hydrogen weapons take priority over control of ordinary atomic weapons? Should the United States propose a separate plan exclusively designed to regulate H-bombs?

The official United Nations proposals for international control of atomic energy apparently involve the

assumption that A-bombs are so unique technically and so menacing as to set them apart from conventional weapons and to justify separate consideration in the United Nations and a separate regulatory system. If the step from A-bombs to H-bombs is considered to be as great as the step from conventional weapons to A-bombs, does it follow that hydrogen warfare should become the subject of a separate control proposal and should receive separate consideration in the United Nations?

Are the technical facts of atomic and hydrogen weapons so intimately related that both must be controlled if either is to be controlled? Are the political facts such that the two problems must be regarded inseparably?

AUTHOR'S COMMENT

Since the H-bomb requires the A-bomb as a trigger, it becomes obvious that the two problems are inseparable.

3. Is the existing United Nations plan technically adequate to control H-bombs?

The United Nations plan has been couched in such a manner that an international agency would possess discretionary authority in defining and controlling materials and processes that may be employed to manufacture nuclear weapons of mass destruction.

For instance, the *Second Report* of the United Nations Atomic Energy Commission defines "atomic

energy" as including "all forms of energy released in the course of, or as a result of, nuclear fission *or of other nuclear transformation.*" "Source material" is taken to mean "any material containing one or more key substances in such concentration as the international agency may by regulation determine." "Key substance" is defined to mean "uranium, thorium *and any other element from which nuclear fuel can be produced, as may be determined by the international agency.*" (p. 71). Similarly, the report defines "nuclear fuel" as "plutonium, U-233, U-235, uranium enriched in U-235, material containing the foregoing, *and any other material which the international agency determines to be capable of releasing substantial quantities of atomic energy through nuclear chain reaction of the material.*" (p. 71.) The *report* likewise observes that: "Dangerous activities or facilities are those which are of *military significance* in the production of atomic weapons. The word "dangerous" is used in the sense of *potentially dangerous to world security.*" (p. 70). [Italics supplied throughout.]

Does such breadth of phraseology mean that manufacturing processes and source materials needed in the production of H-bombs could be properly controlled, through the existing UN plan?

Since nearly 2 years of work were required to formulate the UN plan, can this plan be regarded as adequate for hydrogen weapons so long as the control measures for the atomic energy industry are not explicitly elaborated with the same detail as the arrangements evolved for controlling U-235 and plutonium?

It may also be pointed out that the existing UN plan contains no provision for physically protecting informants who advise the international agency of violations. Might potential informants keep silent for fear of being punished by their national governments? Is this factor important if the existing UN plan were subjected to the added strain of controlling hydrogen weapons as well as atomic weapons?

What safeguards would assure that the employees of an international control agency would be faithful and loyal to the objectives of the agency and that they would not work purely in the interests of some national government—perhaps a national government other than that of their own country?

AUTHOR'S COMMENT

The language makes it obvious that the United Nations plan "foresees and carefully takes into account the possibility of an H-bomb." In view of Russia's attitude, however, and to leave no room for future quibbling, the present plan should be explicitly elaborated to include hydrogen weapons. On the other hand, since Russia will have none of the plan, such elaboration would at best be purely academic.

As for protecting informants, certainly no plan could contemplate that citizens would act as spies against their own country, even if they find that their country is violating an international agreement. The plan is designed so that such violations could be detected by the official employees of the international control agency. Obviously, such official employees stationed in any country should not be nationals of

that country and should be protected by diplomatic immunity. Each country, in selecting its representatives to the control agency, would naturally subject them to a most careful screening as to their character and loyalty, and would use all necessary checks to make certain that they are faithful and loyal to the objectives of the agency.

4. Is control over fissionable materials sufficient to prevent the production of hydrogen bombs? If so, is the existing UN plan adequate to this task?

The technical facts suggest that H-bombs may be regulated in at least two ways: (1) Control over the fissionable material usable as a "trigger" and (2) control over deuterium and tritium.

Perhaps control over *all* fissionable material would give effective control over hydrogen weapons. However, by way of specific example, the introduction to volume VI of the Scientific Information Transmitted to the United Nations Atomic Energy Commission, June 14, 1946–October 14, 1946 (see State Department Publication 2661, pp. 151–152), comments as follows:

It is difficult to define the amount of activity in the illicit production of atomic weapons which is significant. The illicit construction of a single atomic bomb by means of a decade of successful evasion would not provide an overwhelming advantage, if it can be assumed that it would take another decade to produce a second bomb. But the secret production of one bomb per year would

create a definite danger, and the secret production of five or more per year would be disastrous. This report assumes arbitrarily that the minimum unit of noncompliance is the secret production of one atomic bomb per year or a total of five bombs over any period of time. [This example is chosen because UN documents published later omit concrete illustrations, although the stress which these documents place upon international ownership, operation, and management clearly reflects a determination to reduce to the rock-bottom minimum any illicit mining or production.]

Considering that five illicit A-bombs might, under certain circumstances, lead to five illicit H-bombs, what margin of inefficiency—if any—in controlling source and fissionable material is permissible? Is absolute protection against illegal diversion of source and fissionable material technically possible? Does the existing UN plan provide absolute or near-absolute protection? Can greater technical protection be secured than under the present UN plan?

AUTHOR'S COMMENT

It can be stated unequivocally that, in the absence of complete mutual faith and goodwill on the part of all concerned, neither the existing UN plan nor any other technical plan that can be devised will provide absolute or near-absolute protection. No plan could be devised that would provide assurance against the diversion of enough material in any one year to make at least one atomic bomb. In five years this would mean the secret production of five hydrogen bombs.

5. MUST H-BOMB CONTROLS RELATE TO DEUTERIUM AND TRITIUM AS WELL AS TO FISSIONABLE MATERIAL? IF THEY MUST, CAN THE PRESENT UN PLAN FULLY PROVIDE FOR THESE CONTROLS OR DOES IT REQUIRE REVISION OR CHANGES IN EMPHASIS?

Should control over both fissionable material and deuterium and tritium call for the same emphasis and consideration which the United Nations Atomic Energy Commission has already given to control of U-235 and plutonium? Would surveillance of deuterium and tritium manufacture furnish better insurance against illicit H-bomb construction than surveillance of U-235 and plutonium, or is the reverse more apt to be true? Are added safeguards necessary to regulate deuterium and tritium? Or is the UN plan, as now constituted, sufficiently flexible and comprehensive to take care of light-element control?

AUTHOR'S COMMENT

Since H-bombs require either U-235 or plutonium, as well as deuterium and tritium, and since absolute or near-absolute control of U-235 or plutonium is not possible, it becomes obvious that H-bomb controls must relate to both deuterium and tritium as well as to fissionable material. Since the UN plan does not mention them by name, added safeguards are necessary to regulate deuterium and tritium. No safeguards, however, could be devised even in this respect to provide absolute or near-absolute protection.

6. IS IT TECHNICALLY POSSIBLE TO DETECT THE MANUFACTURE OF HEAVY WATER AND DEUTERIUM THROUGH INTERNATIONAL INSPECTION? WOULD AN INTERNATIONAL AGREEMENT FLATLY PROHIBITING PRODUCTION IN QUANTITY BE DESIRABLE?

The manufacture of heavy water and the separation of deuterium are relatively simple processes. They may be carried out in small plants which can exist in a variety of locales.

The *Second Report* of the UN Commission comments as follows:

> The international agency shall have the authority to require periodic reports from nations regarding the production, shipment, location, and use of specialized equipment and supplies directly related to the production and use of atomic energy, such as mass spectrometers, diffusion barriers, gas centrifuges, electromagnetic isotope separation units, very pure graphite in large amounts, heavy water, and beryllium or beryllium compounds in large amounts. In addition, the agency shall have authority to require reports as specified of certain distinctive facilities and construction projects having features of size and design, or construction or operation, which, in combination with their location and/or production or consumption of heat or electricity, are peculiarly comparable to those of known atomic facilities of dangerous character (p. 54).

Would inspectors possessing freedom of movement be able to locate deuterium and heavy water plants? Would aerial surveys and aerial photographs of industrial areas help detect processes which produce hydrogen as a byproduct and which might therefore

be concerned with the manufacture of heavy water or deuterium? Should quantity production of deuterium be prohibited even though it is used in certain types of peacetime reactors such as the Canadian reactor at Chalk River, the French reactor at Chatillon, Swedish reactors under construction, and a research reactor at the Argonne National Laboratory? Is it possible on technical grounds to enforce such a prohibition?

AUTHOR'S COMMENT

It would not be desirable to prohibit production of heavy water and deuterium in quantity since heavy water is the best moderator of neutrons in the large-scale production of atomic power for industrial uses. Furthermore, such a prohibition could never be enforced, since, as stated, the manufacture of heavy water and the separation of deuterium are relatively simple processes that "may be carried out in small plants which can exist in a variety of locales." What makes it even more difficult, if not impossible, to detect any violation of such a prohibition is the fact that the raw material for heavy water or deuterium is just plain water.

7. Should the provisions of the present UN plan relating to inspection, surveys, and explorations be modified to control heavy water and deuterium production?

The United Nations plan assumes that the production of fissionable material cannot be regulated with-

out strict supervision over the mining of source materials such as uranium and thorium:

> Without the control of raw materials, any other controls that might be applied in the various processes of atomic energy production would be inadequate because of the uncertainty as to whether or not the international agency has knowledge of the disposition of *all* raw material. (*Second Report,* p. 30.)

Whereas uranium and thorium are needed to produce U-235, [U-233] and plutonium, the production of deuterium is not subject to such limitation of source materials. Only water, the existence of power, and comparatively simple plants are needed for the manufacture of heavy water and deuterium. In view of these facts, can the existing United Nations plan cope with the problem of regulating deuterium production?

In commenting upon spot aerial surveys, for example, the *Second Report* recommends that "the [international] agency shall conduct spot aerial surveys in each period of 2 years over areas not exceeding 5 percent of the territory under the control of each nation or areas not to exceed 2,000 square miles, whichever is the larger. (These area limitations apply to spot aerial surveys only)" (p. 68). If aerial surveys were to be used not only in controlling raw materials but also to help in spotting deuterium and heavy water plants, must they be carried out more frequently than is provided in the existing plan?

The *Second Report* also indicates that a UN inspectorate should be compelled to secure permission, through a warrant procedure, before inspecting "pri-

vate and restricted property not open to visitation by the population in the locality, and in the case of certain ground surveys and aerial surveys which are additional to others which the agency may conduct without warrant or other special authorization" (p. 60). Do the technical facts surrounding heavy water and deuterium production suggest that such a restriction on an international agency's authority would have to be modified?

AUTHOR'S COMMENT

See comment on question 6.

8. WHAT SAFEGUARDS ARE NECESSARY TO PREVENT CLANDESTINE PRODUCTION OF TRITIUM? WOULD AN INTERNATIONAL AGREEMENT FLATLY PROHIBITING PRODUCTION IN QUANTITY BE DESIRABLE?

U-235 and plutonium may be used either in weapons or as fuels for peacetime reactors. Here is the reason most frequently cited for requiring that international control include not only inspection but also such further guaranties as United Nations ownership, operation, and management of "dangerous" plants. The potentiality, both for good and evil, that characterizes fissionables does not appear to characterize tritium, which has no known peacetime uses except as a laboratory research tool. Is it therefore possible that the reason for requiring inspection plus other guaranties as regards U-235 and plutonium does not apply to tritium and that inspection alone would answer?

If quantity production of tritium were altogether

forbidden—as having no peacetime purpose—the mere act of preparing lithium (the tritium raw material) for irradiation and the mere act of inserting it in a nuclear reactor might be considered a violation. Would such action be impossible to conceal from managers and inspectors stationed at each reactor permitted under the control agreement? Would an illegal reactor itself be impossible to conceal from inspectors enjoying freedom of movement?

A few private commentators have argued that the UN plan fundamentally errs in assuming industrial power to be around the corner. They estimate that this goal is actually a decade or two away and that meanwhile the control problem would be simplified if all high-powered reactors were dismantled. Does the role of reactor-produced tritium in H-bomb production strengthen such an argument?

The UN plan distinguishes between atomic facilities which are sufficiently "dangerous" to require UN management and facilities which may be operated by national governments and merely require international inspection. Since all reactors produce neutrons and hence might be useful in some degree—however small—in manufacturing tritium, is it now necessary to regard certain reactors formerly considered to be "non-dangerous" as now being in the "dangerous" category?

Are there other methods, apart from reactors, for producing tritium? If so, how can they be controlled? Would the right of the international control agency to own, operate, and manage "dangerous" plants and to own and regulate both fissionable materials and "fusionable materials" meet such a situation?

AUTHOR'S COMMENT

The most efficient and rapid method for producing tritium is by inserting lithium metal into a large nuclear reactor, thus exposing it to irradiation by neutrons, which transmute the lithium into tritium and helium. Tritium could also be produced in a similar manner in the smaller nuclear reactors used for research purposes, and though these smaller reactors would produce it at a considerably slower rate, the fact that the amounts of tritium required may be rather small would inevitably shift these reactors from the "non-dangerous" to the "dangerous" category. Such small reactors are essential for research, and their prohibition would strike a vital blow at the progress of science. Furthermore, they could be much more easily hidden than large reactors. This fact, therefore, weakens, rather than strengthens the argument for the dismantling of all high-powered reactors, as such dismantling would not prevent the production of tritium.

There are other, though less efficient, methods for producing tritium, however, that do not require any reactors at all. A good neutron source can be provided by exposing beryllium to radium, radon, or polonium. These neutrons could then be used to bombard lithium and convert it into tritium. Nor is lithium necessary, for at least four other elements, including deuterium, helium 3, boron, and nitrogen, can be transmuted by neutrons from the beryllium into tritium. What is more, even neutrons are not absolutely essential, since deuterons (nuclei of deuterium)

and beryllium could be made to yield tritium by bombarding them with other deuterons. The latter method, however, would require the use of giant cyclotrons and would be very slow.

All this would indicate that it would be extremely difficult, if not impossible, to provide safeguards against the clandestine production of tritium.

9. Should a world-wide geological survey cover concentrated lithium deposits?

A key feature of the United Nations plan is the provision for a world-wide geological survey of uranium and thorium—the raw materials potentially usable in A-bombs. This survey is considered necessary in order to permit tracing of materials as they progress from the mines through various processing phases and finally enter a nuclear reactor. Does the same kind of logic apply to lithium—raw material for tritium? How formidable is the technical problem of locating and controlling deposits of lithium?

Pegmatite minerals constitute a principal source of lithium ores, which are currently produced as a byproduct of the nonmetallic mineral industry. Commercial deposits of lithium are known to exist in the Black Hills of North Dakota; northern New Mexico; Saskatchewan, Canada; and southwest Africa. Production of ores rose to about 900 tons of lithium oxide in 1944 and is now about 200 tons. So long as requirements do not exceed byproduct production, supply does not appear to present a problem. If requirements exceed

byproduct supply, the cost of the excess might be high. Lithium is now used commercially in glass, as a compound in welding fluxes, in storage batteries, in fluorescent light tubes, and as an alloying element.

Are the quantities of lithium ore required on an order of magnitude that makes control feasible?

AUTHOR'S COMMENT

Such a world-wide geological survey would be futile, as only a few hundred pounds of lithium would be necessary to produce enough tritium for a relatively large H-bomb stockpile, and such amounts could be hidden right now from available stocks.

10. DO THE TECHNICAL FACTS OF THE H-BOMB MEAN THAT NOW, MORE THAN EVER, THE UNITED NATIONS PLAN IS THE CORRECT APPROACH TO INTERNATIONAL CONTROL?

Various critics of the UN plan have denied that management control over "dangerous" plants is essential to protect against violations. High-power reactors are among the plants to be classified as "dangerous" under the UN plan, and these same reactors are the ones which might produce not merely plutonium but tritium in quantity. Likewise, an international agency would possess authority to check the design of any isotope separation unit and to assume the right of construction and operation if these fall into the "dangerous" category. Deuterium may be obtained through isotopic separation. Do such facts as these refute the

critics and demonstrate that managerial and material control by the United Nations, over and above inspection, is more than ever necessary in order to prevent diversion of nuclear fuel or illegal irradiation of lithium?

AUTHOR'S COMMENT

In the light of the technical facts about the H-bomb, the argument as to whether managerial control over "dangerous" plants is essential to protect against violations becomes wholly academic. We have seen that even managerial control would not offer either absolute or near-absolute protection. No plan that does not offer at least near-absolute protection against the clandestine production of even one H-bomb per year could be trusted when a nation's very existence may be at stake.

11. How does the H-bomb affect the problem of "stages"?

The United Nations plan would take effect by "stages"—one stage to include, among other projects, a world-wide geological survey, another stage, to involve, among other projects, the taking over of atomic installations, and still another to bring about the disposition of fissionable materials

At what point in some such progression would national stockpiles of deuterium and tritium be placed under control? When this point was reached, would they be destroyed or be held in storage under United Nations auspices? If a nation pretended to make

known its entire stockpile of tritium and deuterium while actually it kept hidden a substantial portion, how would the international agency discover such a violation?

AUTHOR'S COMMENT

See comment on questions 12 and 13.

12. HOW DOES THE H-BOMB BEAR UPON THE PROBLEM OF DISPOSITION OF EXISTING STOCKS OF FISSIONABLE MATERIAL?

When a control plan takes effect, what should be done with supplies of U-235 and plutonium in excess of a quantity immediately usable for peacetime purposes? This problem has received relatively little consideration in the United Nations Atomic Energy Commission. If excess stocks were destroyed, a valuable future source of energy and storehouse of neutrons would be lost. On the other hand, if the stocks were kept in existence under UN guard, seizure by an aggressor state might rapidly permit it to attack with atomic bombs—and innocent countries might have relatively little warning.

Such seizures might quickly lead, under certain circumstances, to the construction of "triggers" for H-bombs. Does this fact tip the balance in favor of destroying excess U-235 and plutonium? Or are these substances still too valuable and too difficult to replace to justify destruction? Is there a third alternative—possibly involving partial destruction or the use of "denaturants" or the construction of many power re-

actors, regardless of cost factors—to keep excess stocks of fissionables contaminated with fission products?

AUTHOR'S COMMENT

The problem of the disposition of existing stocks of fissionable materials was given little consideration because it was too hot to handle. From the very beginning Russia insisted that all atomic bombs be destroyed, and she left no doubt that she meant the destruction of the fissionable materials with which bombs could be quickly assembled. Even before the H-bomb, such destruction might have meant suicide to nations that complied, since they would have been at the complete mercy of noncomplying nations. The advent of the H-bomb makes all talk of such destruction, wholly apart from the waste of a priceless, irreplaceable natural resource, completely unrealistic, as any such act would be tantamount to abdication, a prelude to a super-Munich by the free nations. Denaturing, which makes fissionable materials temporarily useless for bombs, is also out of the question, since it would take a long time to reconcentrate them, giving nations with a hidden stock of nondenatured material a tremendous advantage that might well mean the difference between survival and annihilation for a nation that acted in good faith. All this also applies to the destruction of stocks of deuterium and tritium.

13. How does the H-bomb bear upon "quotas"?

The United Nations plan envisages that reactors and other atomic facilities will be distributed among

the nations according to "quotas" and a "strategic balance"—whereby no one nation, by seizing the plants within or near its borders, could gain an undue military advantage over innocent nations. This "quota" feature has been criticized as unnecessary and as likely to hinder individual countries in developing the peacetime uses of atomic energy to the maximum extent.

Does the fact that reactor fuels, if seized by an aggressor, might make available H-bomb "triggers" tend to render all the more desirable the "quota" idea? How long a time would an aggressor require to make enough deuterium and tritium for H-bombs in seized plants? Could a world-control authority, by requiring that certain design features be incorporated in the plants under its control, extend this time period? What should be done with plants in existence at the time a control agreement takes effect and well suited to H-bomb production but poorly suited to peacetime uses? How should such plants, if they were not dismantled, figure in "quota" allotments?

AUTHOR'S COMMENT

From its very inception the quota system was totally impossible of realization. Today it is likely to prove a snare and a delusion, giving a false sense of security, since it could not guarantee against the clandestine production of at least one H-bomb a year. The plutonium for the trigger could be produced in hidden small reactors, while the deuterium and tritium could be produced in other small plants that could be equally hidden. As we have seen, tritium production does not even require a nuclear reactor.

Like the "quota system," the system of "stages" has also become completely out of date, since it was predicated on the control system taking effect before Russia developed her own atomic bombs or had built her own nuclear reactors. Today there is no longer any logical reason for any stages, since any delay would make effective control more difficult. Even today, if an international agency were to take over stockpiles, it could never be certain that considerable amounts had not been hidden away. In other words, even if the UN plan were to be adopted today, it would not give security against a surprise atomic attack, which is the very purpose of the plan.

14. How does the H-bomb bear upon research to be performed by the United Nations control agency?

Under the United Nations plan, individual nations would be forbidden to engage in atomic weapons research, but such research would be performed by the world control agency itself, as a means of keeping it at the forefront of knowledge in this field and thereby enabling it to detect violations which might otherwise pass unnoticed through ignorance. Is research upon H-bombs so dangerous that not even the world control agency should be allowed to undertake it?

AUTHOR'S COMMENT

If an international agency is ever established, it is obvious that it would have to carry on research on

H-bombs for the same reason that would make it vital for it to carry on research on A-bombs—"to keep at the forefront of knowledge" so that it would be in a position to "detect violations." This would become all the more imperative just because the H-bomb is so much more dangerous.

15. Should technical information regarding the H-bomb be transmitted to the United Nations as a basis for a discussion of hydrogen control?

In 1946 the United States transmitted six volumes of technical information on atomic energy to the United Nations. This was one important means of providing members of the United Nations Atomic Energy Commission with sufficient basic data to discuss international control.

No similar body of material on hydrogen bombs has been transmitted to the United Nations. Can the Commission now discuss the control of hydrogen warfare without further official information on its technical aspects? If such information is to be provided, who should be the provider, the United States or the Soviet Union, or both?

AUTHOR'S COMMENT

All the information so far has come from the United States. In fact, the Smyth Report, the six volumes of technical information submitted to the UN, the testimony by scientists at the Congressional hear-

ings on the McMahon Act, and much declassified information have been of invaluable aid to Russia in developing her own atomic bomb. It is about time that this one-way flow of information came to a stop. Not a trickle has so far come out of Russia—not even an official acknowledgment that she has exploded her first A-bomb—and until she shows her willingness to co-operate fully, we must stop playing Santa Claus.

16. Should a new panel of experts analogous to the Acheson-Lilienthal Board be appointed to study the H-bomb in relation to international control?

It is now more than 4 years since the Acheson-Lilienthal Board made its recommendations on international control. Their findings have since been largely incorporated into the UN plan.

Do the events of the last 4 years make it desirable, for technical reasons, to rethink the control problem? Are the technical data of hydrogen bombs such, as to demand a recasting and change of emphasis in the existing UN plan? Have the prospects of large-scale peacetime applications of atomic energy sufficiently changed that a different orientation in control measures is desirable?

If re-examination of the control question is indicated, should this inquiry be undertaken in the first instance by a group of qualified Americans? Or should the United States suggest that an internationally constituted board initially take on this assignment?

Considering the strong Soviet opposition to the UN plan, is it useful to consider the problem of control? Is the Soviet attitude at all likely to change in the foreseeable future? Would a rethinking of the control problem contribute to a solution unless Soviet representatives participated? Would the appointment of a new "Acheson-Lilienthal Board" raise false hopes?

AUTHOR'S COMMENT

As indicated in Chapter IV and in the preceding comments, the UN plan for the international control of atomic energy is wholly out of date, and the sooner we realize it, the better for us and for the world. It was at best a noble ideal, which did not have the slightest chance of realization from the very start. A re-examination of the entire problem, even before the advent of the H-bomb, had been long overdue. Today it is all the more imperative. Since such a re-examination requires, or at least implies, the withdrawal of the plan, originally sponsored by this country, it should be done by an international board, preferably at the suggestion of some nation other than the United States.

The new board, in considering the whole problem anew, should avoid our original error of regarding control of atomic weapons as a problem wholly separate from that of other weapons of mass destruction. It should recognize the facts of life and not aim at bringing the millennium overnight. It should not seek absolute security, since the facts show it to be unattainable. Rather should it accept as a wise maxim that even partial security is better than none.

If the board set for itself certain limited objectives,

they would have a much better chance of universal acceptance than if its aims were too high, as they were in the original United States plan, now the plan of the majority of United Nations. Its first limited objective should be a general agreement to outlaw the use of all weapons of mass destruction against civilian populations. This would mean outlawing the use not only of A- and H-bombs against large urban centers of population, but also of all other conventional weapons for the mass killing of noncombatants.

A second limited objective should be the outlawing of radiological warfare in all forms, which should include the use of the rigged H-bomb as well as the use of A-bombs in a manner that takes advantage of their radioactive effects. This would mean the prohibition of the explosion of A- or H-bombs from a low altitude, or their explosion underwater in a harbor.

These limited objectives would still permit nations to manufacture atomic weapons and to use them as tactical weapons against military personnel, while they would eliminate their use as strategic weapons against large urban centers. The very possession of atomic weapons by both sides, however, may in itself prevent their use even tactically. In fact, there would still be the hope that they would serve as effective deterrents against war itself.

The advantage of such a plan of limited objectives is the likelihood, or at least the possibility, that even Russia would not dare to turn it down and thus stand before the world as preventing the prohibition of the use of atomic weapons against civilian populations. And once we reached agreement with Russia on one

set of limited objectives, the door may possibly have been opened for further agreement on other limited objectives.

Peace, step by step, appears to be the only alternative to possible catastrophe. One limited objective after another must become our major policy.